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CLIMACS: A Computer Model of Forest Stand Development for Western Oregon and Washington

Virginia H. Dale and Miles Hemstrom

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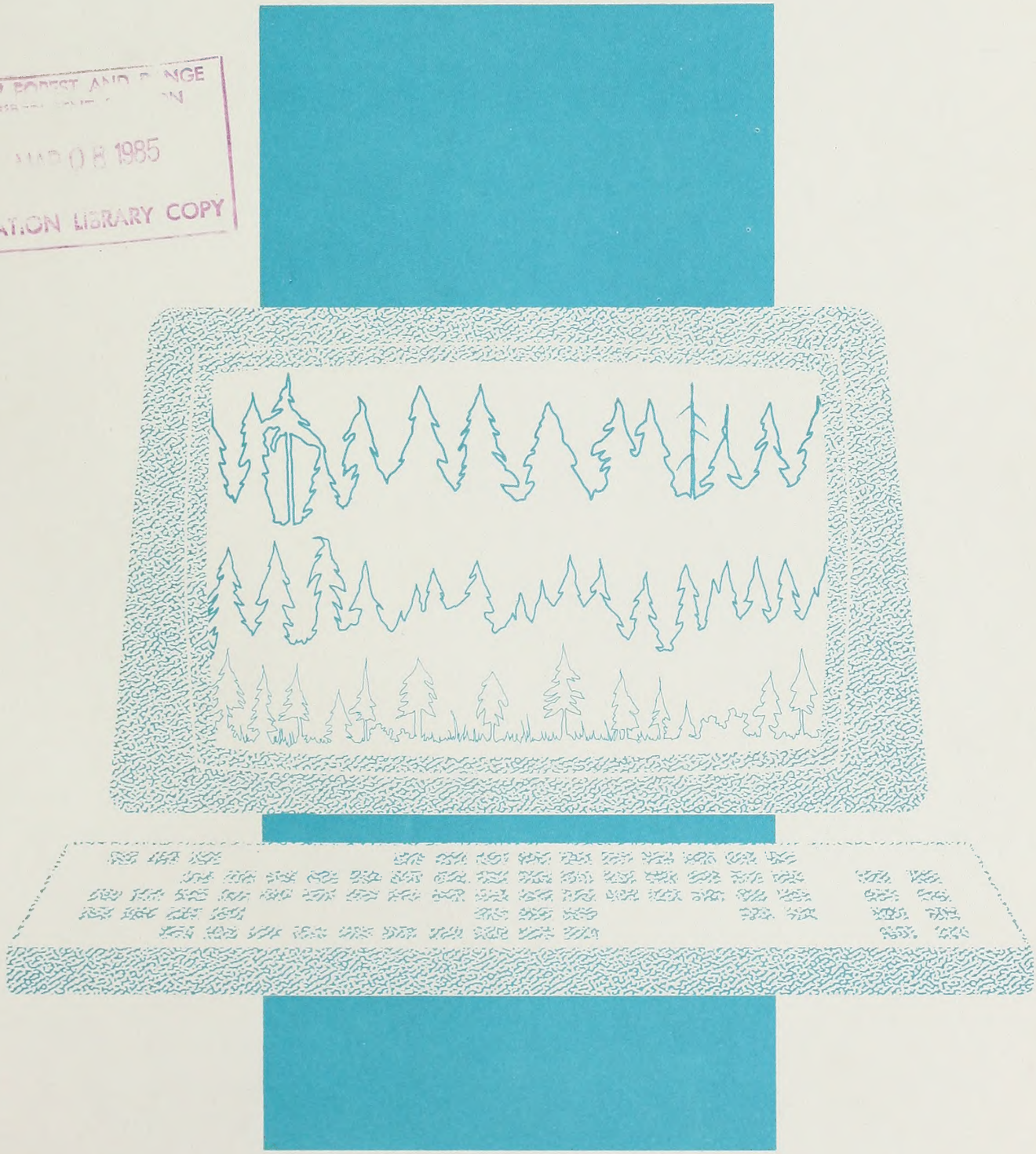

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Abstract

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A simulation model for the development of timber stands in the Pacific Northwest is described. The model grows individual trees of 21 species in a 0.20-hectare (0.08-acre) forest gap. The model provides a means of assimilating existing information, indicates where knowledge is deficient, suggests where the forest system is most sensitive, and provides a first testing ground for hypotheses. Model verification simulations are included for up to 500 years on various sites. Fire, wind, or clearcutting can occur at intervals and intensities specified by users. The model was developed by modifying an existing forest succession simulator of eastern deciduous forests. Birth, growth, and death of individual trees are functions of existing light and temperature conditions, competition and species characteristics. Modifications of the existing simulator include tree height growth being related to temperature and moisture conditions, the foliage biomass to diameter relationship being more realistic, and five mortality classes and shade tolerance classes being defined.

Keywords: Succession, models, simulation, community dynamics (plant).

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Introduction

CLIMACS (Computer Linked Integrative Model for Assessing Community Structure) is a simulation model of forest succession for western Oregon and Washington. The model tracks characteristics of individual trees growing in a forest opening of 0.20 hectare (0.08 acre). The FORTRAN IV code of CLIMACS is based on FORET (Shugart and West 1977), a succession model for eastern Tennessee, which in turn was modified from JABOWA (Botkin and others 1972), a simulator for forests of the northeastern United States. CLIMACS retains the stochastic features of the succession models for the eastern deciduous forests and has a more elaborate diameter increment equation and treatment of mortality. A moisture stress index is incorporated into the function that calculates diameter increment, and height growth is dependent upon site quality for some species. Mortality is related to the size of the tree and the successional status of the species under consideration. Three types of disturbance can occur: fire, wind, or clearcuts.

The model paradigm represents our view of succession as the result of individual tree processes and episodic disturbances. The term "climax" is tenuous because pioneer species are so long-lived that climax forests rarely develop in the Pacific Northwest even though major disturbances are infrequent. Although the simulator should be realistic enough to approximate stand development on particular sites, its main value is in summarizing and testing current hypotheses about tree growth and the factors affecting succession. The model is an exercise that should be useful to managers to examine hypotheses of the long-term effects of human activities on stand development.

A review of forest succession models is presented by Shugart and West (1980). According to their terminology, CLIMACS is a gap model that simulates characteristics of individual trees in a small portion of the forest—either an opening in the canopy or a sample plot. Such models are particularly useful for evaluation of long-term and large-scale changes in the environment and the effects of those changes on forest succession.

The purpose of this paper is to clarify algorithms and subroutines of the model. The basic features of the model are described in Botkin and others (1972) and Shugart and West (1977). Following the standards for model documentation from Swartzman (1979), the assumptions of the model are set forth, the value and source of each parameter is given, the source of the equations and potential problems of the curve forms are indicated, and the logic of the FORTRAN program is presented. This paper describes the structure of the main program and discusses the four major subroutines: BIRTH, GROW, KILL, and DISTRB. Results for several forest sites are presented.

The model code is stored on computer tape at the Forest Science Data Bank, Department of Forest Science, Oregon State University, Corvallis, Oregon.

Table 1—State variables[1]

Name	Definition	Units	Subroutines
A(KYR,i)	Aboveground biomass for species	t/ha	MAIN, OUTPUT, PLTREE
A(KYR, NSPEC+2)	Total number of trees per plot		
A(KYR, NSPEC+3)	Leaf area index for plot	m^2/m^2	PLTREE, OUTPUT, MAIN
A(KYR, NSPEC+1)	Stand biomass	t/ha	
DBH(j)	Diameter at breast height of tree j	cm	SPROUT, KILL, GROW, OUTPUT, BIRTH
IAGE(k)	Age of tree k	yrs	GROW, KILL, SPROUT
NTREES(i)	Number of trees of species i		SPROUT, GROW
BIOM	Stand biomass = A(KYR,i)	t/ha	PLTREE
BAREA	Basal area of stand	m^2/ha	PLTREE
A(KYR1, 26)	Total foliage biomass	t/ha	OUTPUT, PLTREE
FB(i)	Foliage biomass for species	t/ha	OUTPUT, PLTREE
D(i,k)	Number of stems of species i in diameter class (k*10) to (k*10 + 10)		PLTREE

[1]Numbers that represent the current state or condition of the system.

Structure and Assumptions

The model updates and records on an annual basis characteristics of all individual trees greater than 10 cm diameter at breast height (d.b.h.) on a 0.20-hectare (0.08-acre) plot (table 1). In the model, foliage is distributed vertically but not horizontally (Cartesian coordinates of each tree are not recorded). The driving variables (numbers that are inputs to the model and are not affected by the components of the system) for the model are plant moisture stress (PMS) (-bars) and temperature growth index (TGII) (days). PMS is the predawn negative xylem pressure measured near the end of the growing season (Waring and Cleary 1967). TGII is from a temperature summation formula that weighs temperatures by their effects on the production of seedlings of *Pseudotsuga menziesii* (Mirb.) Franco (Cleary and Waring 1969). In the model, the yearly temperature growth index (TGI) varies from year to year in a normal distribution around the driving variable TGII. The model has six major assumptions:

1. PMS and TGII reflect the main physical driving variables of forest succession.
2. Competition for light is the primary biological factor affecting forest succession.
3. Regeneration of species that can grow under existing light and soil conditions is stochastic within the bounds of the geographic distribution of the species.
4. Diameter increment can be modeled as a multiplicative function of tree size, photosynthetic rate as reflected in foliage biomass, nutrient competition, light availability, shade tolerance, and moisture and temperature stress.
5. Mortality can occur at two levels—an individual tree and a portion of the stand.
6. Individual tree mortality is conditioned by growth rate.

A listing of the entire program is given in Appendix 1.

The model can be applied to four geographic regions west of the Cascade Range: Santiam Pass south to the California border, Santiam Pass north to Mount Rainier, north of Mount Rainier to the Canadian border, and the Olympic Peninsula (fig. 1). Restriction of a model run to a geographic region limits the species in the succession model to those found naturally in the region.

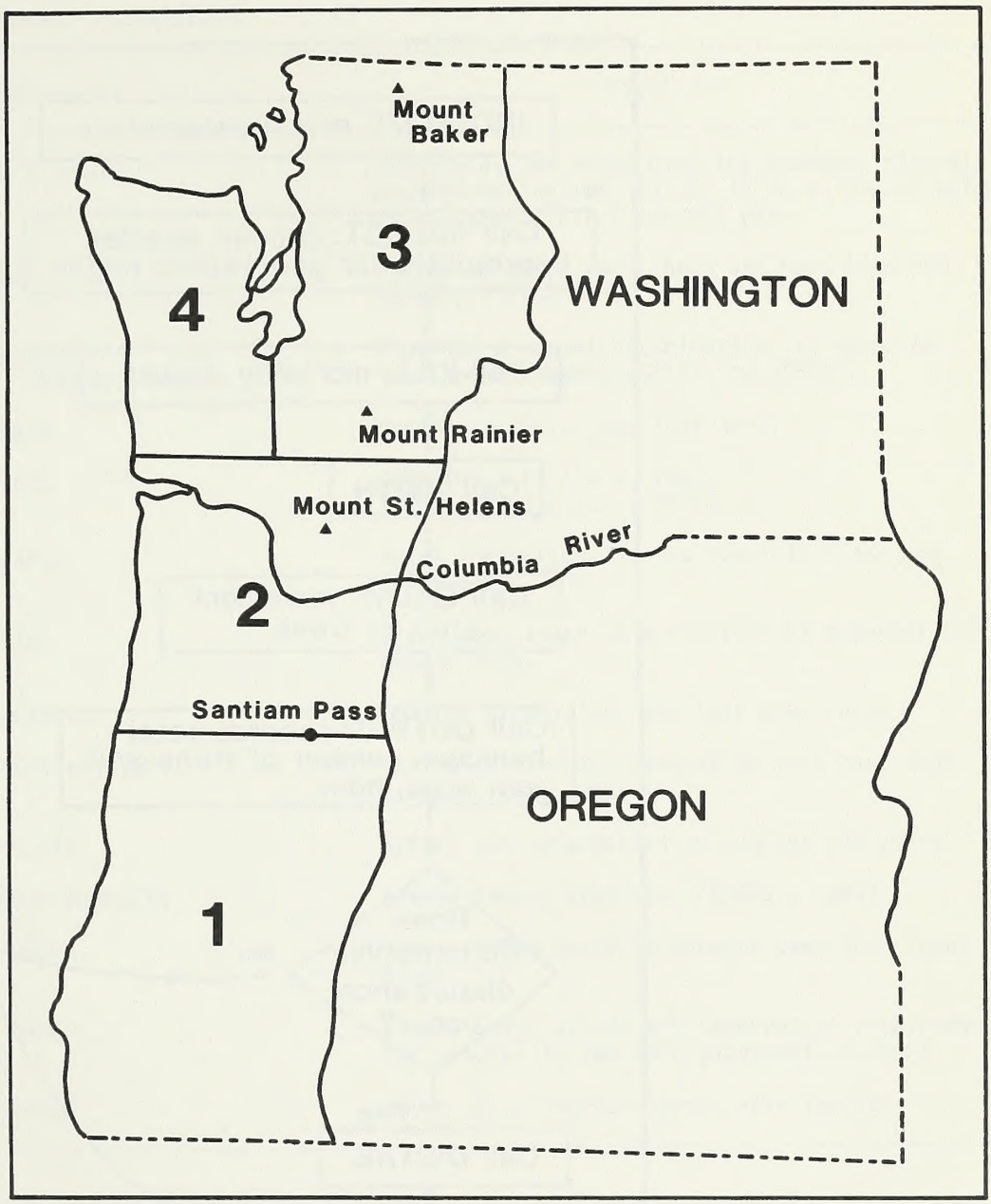

Figure 1.—The model is applicable to four geographic regions in Oregon and Washington.

Main Program

The main program manages the entire model by initializing the year and plot replicate counters, setting the data storage array to zero, and calling the major subroutines as outlined in figure 2. A successional sequence can occur on replicate plots and for as many years as specified by the user. The model can start from a bare plot (see subroutine BIRTH), or the user can read in the species and diameter of each tree on the plot (see subroutine INPUT). The names and parameters of the species, driving variables, and length of the model run are read in by a call from the main program to subroutine INPUT. For each year of the simulation the appropriate species for the site are selected (subroutine SELECT), trees can die (subroutine KILL), regeneration occurs (subroutine BIRTH), and the diameter of

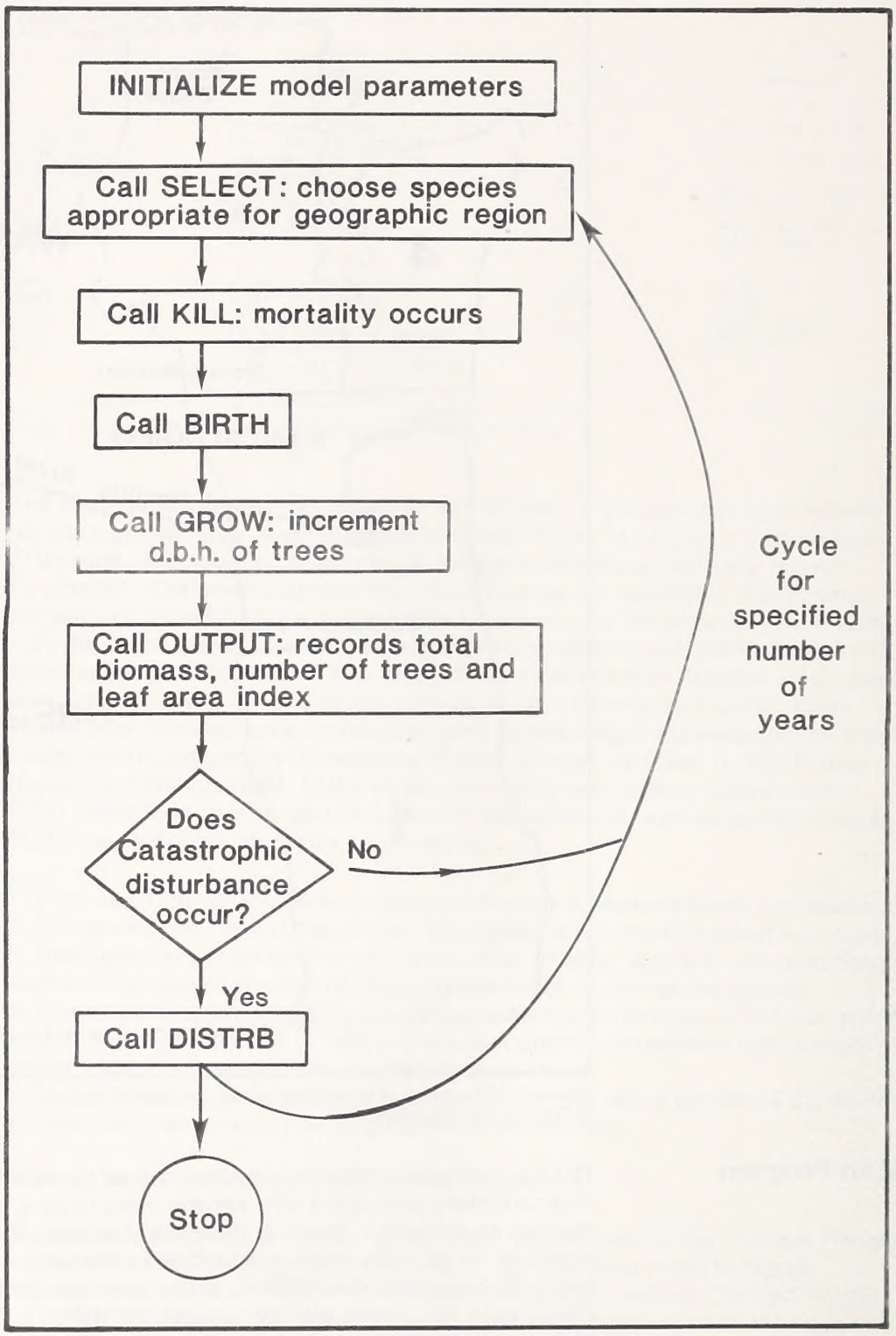
INITIALIZE model parameters
Call SELECT: choose species appropriate for geographic region
Call KILL: mortality occurs
Call BIRTH
Call GROW: increment d.b.h. of trees
Call OUTPUT: records total biomass, number of trees and leaf area index
Does Catastrophic disturbance occur?
No
Yes
Call DISTRB
Stop
Cycle for specified number of years

Figure 2.—General scheme of model.

Table 2—Subroutines

Subroutine	Discussion
BIRTH(KYR)	Introduces new trees with the diameter randomly distributed between 10 and 15 cm at breast height of the tree. KYR = current year.
ERR	Indicates error when there are more than 700 trees per plot.
GGNORD (NSEED1, NSEED2, Z)	Provides a normal distribution, Z, based on the random numbers NSEED1 and NSEED2.
GROW	Growth of d.b.h. and leaf area.
INIT	NOGRO(I) = 0, I = 1, 700; KSPRT(I) = 1, I = 1, NSPEC.
INPUT	Reads and writes species specific names and parameters.
KILL	Eliminates trees as a function of diameter and growth rate.
OUTPUT	Updates biomass and the leaf area index.
PLOTIN(IPLOT)	Variables to start simulation in a bare plot (IPLOT = plot number).
PLTREE	Writes out information on species and years.
RANDOM(NSEED)	Random number generator (NSEED = seed).
RANSEE	Reads random number generator seed from input file.
SELECT	Checks water stress and temperature requirements for species in the four geographic regions.
SPROUT	Stump sprouting for appropriate species.

existing trees increases (subroutine GROW). A discussion of each subroutine is given in table 2. For specified years, stand and species characteristics are printed out in tabular form (see Appendix 2).

Definitions of the constants, indices, and parameters are given in tables 3, 4, 5, and 6. The parameter values are appropriate for species in the Pacific Northwest and their sources are indicated in tables 7, 8 and 9.

Table 3—Constants

Name	Value	Definition	Units	Subroutines
soilq	100000.0	Maximum biomass for forests in the area	kg/ha	GROW, MAIN
size	10.0	Mean d.b.h. of new trees	cm	SPROUT, BIRTH
PI2	6.283	2π		GGNORD
phi	1.0	Proportion of annual light attenuation constant		GROW
tinc	.1	Minimum growth of d.b.h. per year to trigger mortality	cm	GROW

Table 4—Indexes

Index	Range	Meaning
i	1 - NSPEC	Species of tree
j	1 - NTOT	Individual tree
KYR	1 - NYEAR	Model year
IPLOT	1 - total number of plots	Plot number

Table 5—Parameters

Name	Definition	Units	Source of values or relationships	Subroutines
AAA(i,j)	Array of species names			KILL, GROW, INPUT
$A_1(i)$	Intercept for stemwood	kg	Gholz and others (1979)	KILL, INPUT, GROW, OUTPUT
$A_2(i)$	Intercept for the foliage	kg	Gholz and others (1979)	KILL, INPUT, GROW,
AL[1]	Available light		(See GROW)	GROW
AREA[1]	Total leaf area	m^2/m^2	(See OUTPUT)	OUTPUT
ATOT[1]	Total number of trees in plot		(See OUTPUT)	OUTPUT
BAR(i)[1]	Total aboveground wood and foliage biomass	t/ha	Gholz and others (1979)	OUTPUT
BB(i)	Slope for stemwood biomass		Gholz and others (1979)	INPUT, KILL, GROW, OUTPUT
BC(i)	Slope for total foliage biomass equation		Gholz and others (1979)	OUTPUT, KILL, GROW, INPUT
$B_1(i)$	Coefficient relating tree volume growth to leaf biomass		Reed and Clark (1979)	INPUT
$B_2(i)$[1]	Height parameter		Botkin and others (1972) (calculated from DBHMX and HMAX) (see GROW)	BIRTH, INPUT, KILL, GROW
$B_3(i)$[1]	Height parameter			
$B_4(i)$	Exponential relating tree volume growth to leaf biomass		Reed and Clark (1979)	INPUT
C(i)	Conversion from leaf mass to area	m^2/kg	Gholz and others (1979)	KILL, GROW, INPUT
DBHMX	Maximum diameter at breast height	cm	Franklin and Dyrness (1973)	KILL, GROW, INPUT
DMAX(i)	Maximum number of degree growing days	days	Emmingham and Waring (Personal communication)	KILL, SELECT, GROW, INPUT
DNC[1]	Diameter increment shading and competition	cm	Modified from Botkin and others (1972) (see GROW)	GROW
FBIO[1]	Total foliage biomass	kg	Gholz and others (1979)	GROW, OUTPUT, BIRTH
FI	Fire intensity ($0 \leq FI \leq 1$)			DISTRB
HMAX(i)	Maximum height of species i	dm	See Table 7	INPUT
HT[1]	Tree height	dm	(See GROW)	GROW
IGEOG	Geographic region			INPUT, GROW, SELECT, KILL
IHT[1]	Decimeter height class for trees		(See GROW)	GROW
IREG(j,IGEOG)	Indicates species availability in geographic region IGEOG			KILL, SELECT, BIRTH, INPUT
ISEL(i)	Summarizes whether species can occur in a region			KILL, SELECT, BIRTH, GROW
ITOL(i)	Indicates shade tolerance		(See GROW)	KILL, GROW, INPUT
MPLANT	Randomly chosen number of species to plant (0 to 8)			BIRTH
NCODE(i)	Species code number			BIRTH, GROW, SPROUT, OUTPUT, KILL, PLTREE
NTOT	Total number of trees in plot			KILL, SPROUT, GROW, OUTPUT, BIRTH
P	Probability a tree survives a disturbance (wind or fire)		(See DISTRB)	DISTRB
PR	Probability a tree species survives 1 year of slow growth		(See KILL)	KILL
NSPRT	Randomly selected number of trees to sprout			BIRTH, SPROUT
SBIO[1]	Total foliage biomass and stem wood biomass (without bark) except for alder	t/ha	Gholz and others (1979) (See GROW)	GROW
SLAR	Shading leaf area, leaf above that of size (dm) of tree	m^2/m^2	(See GROW)	GROW
SPNAM(i)	Alphanumeric species names being considered			
SPRTMN(i)	Minimum d.b.h. for sprouting to occur	cm		KILL, GROW, INPUT
SPRTMX(i)	Maximum d.b.h. for sprouting	cm	DBHMX except for alder	KILL, GROW, INPUT
SPRTND(i)	Average number of sprouts on death of main stem			SPROUT, KILL, GROW, INPUT
SUMLA(IHT)	Sum of leaf area of trees in dm size class IHT (latter of all dm classes)	m^2/m^2		GROW
WMIN(i)	Minimum value of water stress	bars		SELECT, GROW, KILL, INPUT
WATDEX[1]	Moisture index		(See GROW)	GROW
Z(K)[1]	Normal distribution		(See GGNORD)	GROW, GGNORD

[1]Calculated parameters.

Table 6—Internal parameters[1]

Name	Definition	Subroutine
KSPRT(i)	= -1 if sprouting occurs = 1 if no sprouts	KILL, SPROUT, INIT
KLAST	=KTIMES, current iteration	MAIN
KYR	Current year (0 KYR NYEAR)	MAIN
NCT	Keeps track of number of years in the main program	MAIN
KYR1	KYR = 1	MAIN, OUTPUT, BIRTH
NG	Number of trees not growing	KILL, GROW
N1	NSPEC + 1	OUTPUT
N2	NSPEC + 2	OUTPUT, NSPC
NSPC	Species to sprout iteration	SPROUT
NUM	Species number (1 = NUM = NSPEC)	INPUT
NSP	Randomly selected species to plant	BIRTH
NEW	Possible species to sprout	KILL, SPROUT
NEWTR	Species of possible new trees	KILL, GROW
NOGRO(i)	Equals 0 if tree is not growing	INIT, KILL, GROW
RANDOM	Random number	
RAT	Random number which is fixed for year	BIRTH
ZNYR	KLAST	MAIN

[1]Those that keep track of processes in the FORTRAN program itself.

Table 7—Parameter values for CLIMACS

Species	SPRTMN	SPRTMX[1]	KTIME	Growth Parameters[2] A1	A2	BB	BC	C	WMIN[3]
Abies amabilis	0	0	9999	-3.5057	-4.5490	2.5744	2.1926	15.2000	18
Abies grandis	0	0	9999	-3.7389	-3.4660	2.6825	1.9278	13.1000	18
Abies lasiocarpa	0	0	9999	-3.7389	-3.4660	2.6825	1.9278	13.2000	10
Abies procera	0	0	9999	3.7158	-4.8730	2.7592	2.1683	13.2000	18
Acer macrophyllum	10	50	9999	-3.4930	-3.7650	2.7230	1.6170	26.1000	18
Alnus rubra	10	75	9999	0	0	0	0	28.2000	8
Arbutus menziesii	10	120	9999	-3.7080	-3.1230	2.6580	1.6930	12.6000	30
Castanopsis chrysophylla	10	90	9999	-3.7080	-3.1230	2.6580	1.6930	12.6000	20
Chamaecyparis nootkatensis	0	0	9999	-2.0927	-2.6170	2.1863	1.7824	17.7000	10
Libocedrus decurrens	0	0	9999	-2.0927	-2.6170	2.1863	1.7824	17.7000	27
Picea engelmannii	0	0	9999	-3.7389	-3.4660	2.6825	1.9278	17.4000	8
Picea sitchensis	0	0	9999	-3.7389	-3.4660	2.6825	1.9278	17.4000	5
Pinus contorta	0	0	9999	-2.9849	-3.6190	2.4287	1.8362	17.4000	15
Pinus lambertiana	0	0	9999	-3.9840	-4.0230	2.6667	2.0327	17.4000	25
Pinus monticola	0	0	9999	-4.2847	-3.9740	2.7180	2.0039	17.4000	10
Pinus ponderosa	0	0	9999	-4.4907	-4.2610	2.7587	2.0967	17.4000	20
Pseudotsuga menziesii	0	0	9999	-3.0396	-2.8460	2.5951	1.7009	17.4000	25
Quercus garryana	10	90	9999	-3.4930	-3.1230	2.7230	1.6930	12.6000	25
Thuja plicata	0	0	9999	-2.0927	-2.6170	2.1863	1.7824	17.7000	10
Tsuga heterophylla	0	0	9999	-2.1720	-4.1300	2.2570	2.1280	20.4000	18
Tsuga mertensiana	0	0	9999	-4.8164	-3.8170	2.9308	1.9756	20.4000	10

[1]SPRTMX = DBHMX except for Alnus rubra which does not sprout from large trees.

[2]Gholz and others (1979).

[3]Zobel and others (1976), Waring (1969), and Waring, personal communication.

Table 8—Parameter values for moisture index

SPECIES	Degree Days		Height Parameters				
	Max.	Min.	B3	B2	ITOL	AGEMX	SPRTND
Abies amabilis	80	20	0.22	85.60	5	450	0
Abies grandis	100	50	.21	76.05	3	350	0
Abies lasiocarpa	60	20	.78	95.18	3	350	0
Abies procera	70	30	.19	68.29	2	450	0
Acer macrophyllum	115	85	.55	55.48	3	250	3
Alnus rubra	90	45	.54	81.68	2	150	3
Arbutus menziesii	130	75	.16	38.35	2	200	3
Castanopsis chrysophylla	130	60	.14	74.73	2	150	3
Chamaecyparis nootkatensis	60	20	.23	69.29	4	1500	0
Libocedrus decurrens	130	60	.30	72.72	4	750	0
Picea engelmannii	60	20	.46	92.94	2	650	0
Picea sitchensis	90	60	.14	64.03	3	450	0
Pinus contorta	70	20	.52	77.63	1	200	0
Pinus lambertiana	130	70	.34	85.81	3	450	0
Pinus monticola	70	40	.16	63.79	3	450	0
Pinus ponderosa	130	100	.38	93.81	1	650	0
Pseudotsuga menziesii	130	30	.23	80.44	2	1000	0
Quercus garryana	130	100	.29	52.51	1	350	3
Thuja plicata	90	45	.23	64.71	4	750	0
Tsuga heterophylla	95	35	.27	81.21	5	600	0
Tsuga mertensiana	55	20	.07	75.97	4	750	0

Table 9—Parameter values for shade tolerance equation

Species	IREG[1]				DBHMX[2]	B1[3]	HMAX[2]	B4[3]	DRANGE
	1	2	3	4					
Abies amabilis	1	1	1	1	183	15612	6096	0.9	1.25
Abies grandis	1	1	0	0	183	12493	7096	1.0	1.31
Abies lasiocarpa	1	1	1	1	61	7404	3040	1.0	1.25
Abies procera	1	1	1	0	220	54435	7920	.9	0.82
Acer macrophyllum	1	1	1	1	50	19044	1524	1.2	.37
Alnus rubra	1	1	1	1	75	130	1320	2.0	.24
Arbutus menziesii	1	1	0	1	120	5047	2438	1.1	1.38
Castanopsis chrysophylla	1	0	0	0	90	15192	3500	1.1	1.38
Chamaecyparis nootkatensis	1	1	1	1	150	3135	5334	1.1	1.73
Libocedrus decurrens	1	0	0	0	120	2243	4500	1.0	1.73
Picea engelmannii	1	1	1	0	102	3313	4877	.9	1.31
Picea sitchensis	0	0	1	1	230	12391	7500	1.0	1.31
Pinus contorta	1	1	1	1	75	6650	3048	1.0	.78
Pinus lambertiana	1	0	0	0	125	12233	5500	.9	1.13
Pinus monticola	1	1	1	1	205	15645	6675	.9	1.04
Pinus ponderosa	1	0	0	0	125	14377	6000	.9	1.14
Pseudotsuga menziesii	1	1	1	1	220	13193	9000	1.1	1.00
Quercus garryana	1	1	0	0	90	4956	2500	1.1	.74
Thuja plicata	1	1	1	1	300	3186	6000	1.0	1.73
Tsuga heterophylla	1	1	1	1	122	17645	6858	.9	1.47
Tsuga mertensiana	1	1	1	1	102	9098	4572	1.0	1.11

[1]Values from Fowles (1965).

[2]Values from Franklin and Dyrness (1973), Fowles (1965), and Pardo (1973).

[3]Adjusted form values given in Reed and Clark (1971) so that a given DBH increment is reasonable.

Subroutine BIRTH

The subroutine BIRTH is based on the FORET model of Shugart and West (1977) (figure 3 presents a flow chart for the routine). Species available for regeneration are selected depending on the existing water stress, temperature range, and geographic region of the plot.

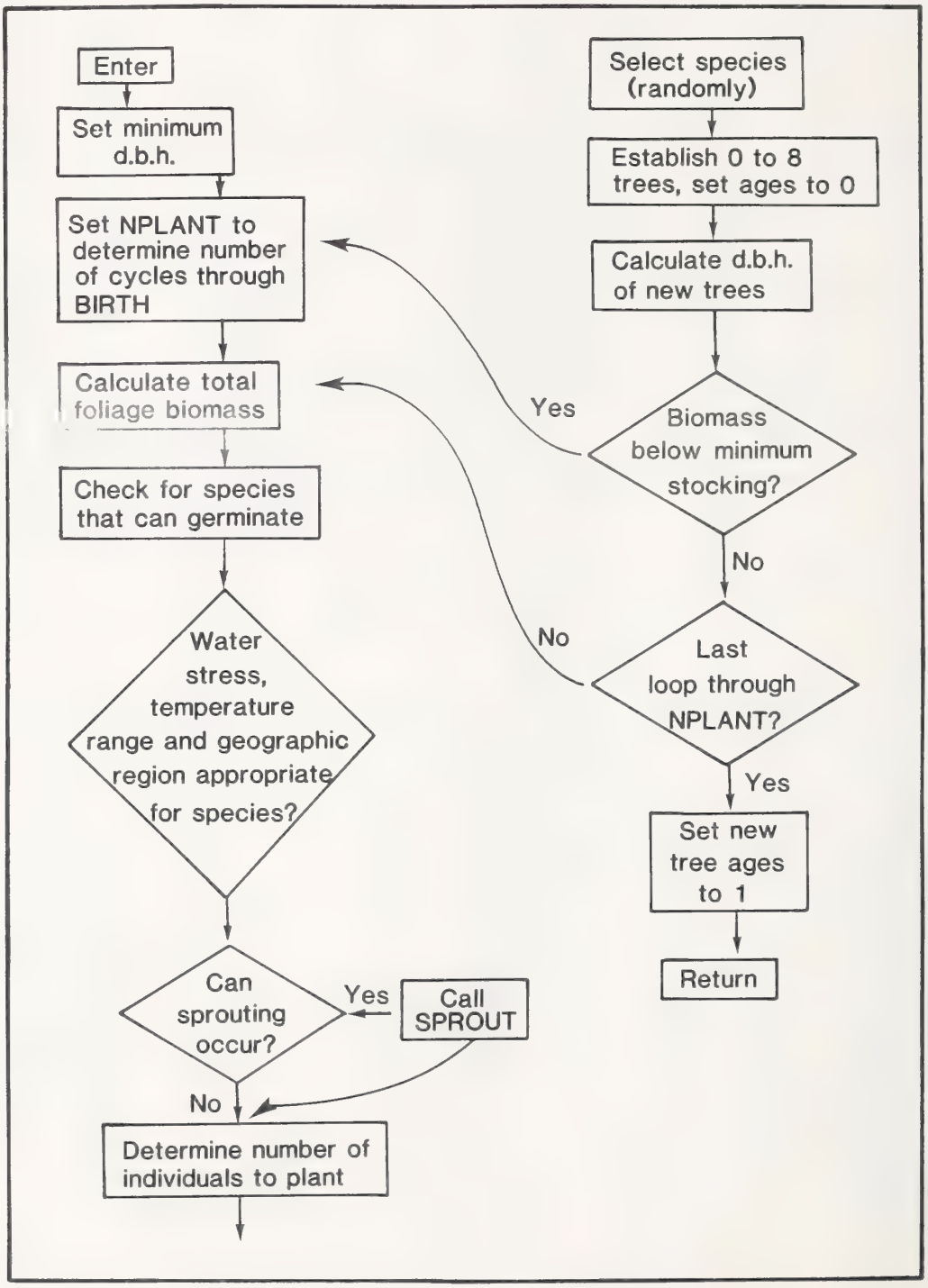

Figure 3.—Flow chart for subroutine BIRTH.

Regeneration depends on the projected leaf area of any existing trees. During the first year any available species can regenerate. Thereafter if the projected leaf area is greater than 3 m^2/m^2 (square meter of leaf area per square meter of ground), *Pinus contorta* Dougl. ex Loud., *P. ponderosa* Dougl. ex Laws., and *Quercus garryana* Dougl. ex Hook. cannot regenerate. If the projected leaf area is greater than 6 m^2/m^2, then *Abies procera* Rehd., *Alnus rubra* Bong., *Arbutus menziesii* Pursh, *Castanopsis chrysophylla* (Dougl.) A. DC., *Picea engelmannii* Parry ex Engelm., and *Pseudotsuga menziesii* cannot appear in the plot. For a projected leaf area exceeding 8 m^2/m^2 *Abies grandis* (Dougl. ex D. Don) Lindl.), *A. lasiocarpa* (Hook.) Nutt., *Acer macrophyllum* Pursh, *Picea sitchensis* (Bong.) Carr., *Pinus lambertiana* Dougl., and *P. monticola* Dougl. ex D. Don cannot appear. If the projected leaf area exceeds 10 m^2/m^2, *Libocedrus decurrens Torr.*, *Chamaecyparis nootkatensis* (D. Don) Spach, *Thuja plicata* Donn ex D. Don, and *Tsuga mertensiana* (Bong.) Carr. cannot regenerate. At leaf areas exceeding 10 m^2/m^2 only the most shade tolerant species, *Abies amabilis* Dougl. ex Forbes and *Tsuga heterophylla* (Raf.) Sarg., can regenerate. The trees appear in the plot when they are between 10 and 15 cm d.b.h. This limit on size is necessary because numbers of smaller seedlings become so large that computer time is prohibitive, and the abundance of very small seedlings may not reflect the composition of an understory that could replace large-canopy trees.

The projected leaf area (XLAI) (in m^2/m^2) is based on foliage biomass (FB10) of all trees on the plot. The equations for the foliage biomass of trees less than 50 cm (19.7 in) in diameter are from Binkely (1983) for *Alnus rubra* and from Gholz and others (1979) for all other species. Because the data range of Gholz' equations is exceeded for large trees (DBH $>$ 50) (fig. 4), the equations for the foliage bio-

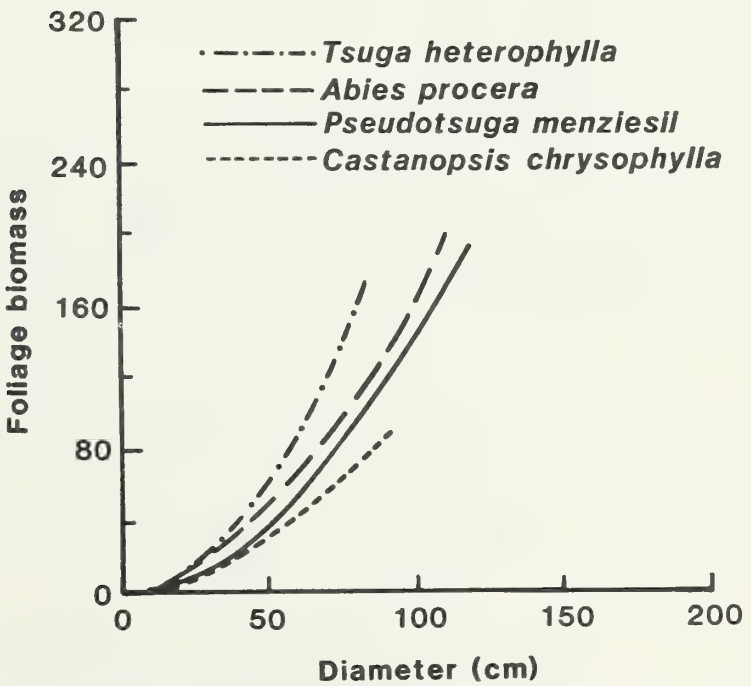

Figure 4.—Foliage biomass as related to diameter using the equations of Gholz and others (1979). A warning is given by Gholz and others (1979) that "maximum and minimum values from the data set...do not necessarily mean that the equation provides reasonable numbers at these extremes." Because of problems in exceeding the data ranges, the foliage biomass-d.b.h. relationship was modified using figure 5, as described in the text.

mass of large trees are calculated indirectly. The sapwood-diameter equation for *Pseudotsuga menziesii* has been obtained by regression analysis.[1/] Foliage biomass can then be calculated from the foliage biomass-sapwood area ratio (Grier and Waring 1974) (fig. 5). To estimate the foliage biomass for large trees of other species, a multiplier is calculated from the ratio of the foliage biomass at 50 cm diameter of the species being considered to that of *P. menziesii* at 50 cm diameter. The multiplier is used to adjust the foliage biomass equations from Gholz and others (1979) for trees larger than 50 cm.

[1/]Personal communication, R. H. Waring, School of Forestry, Oregon State University, Corvallis, Oregon.

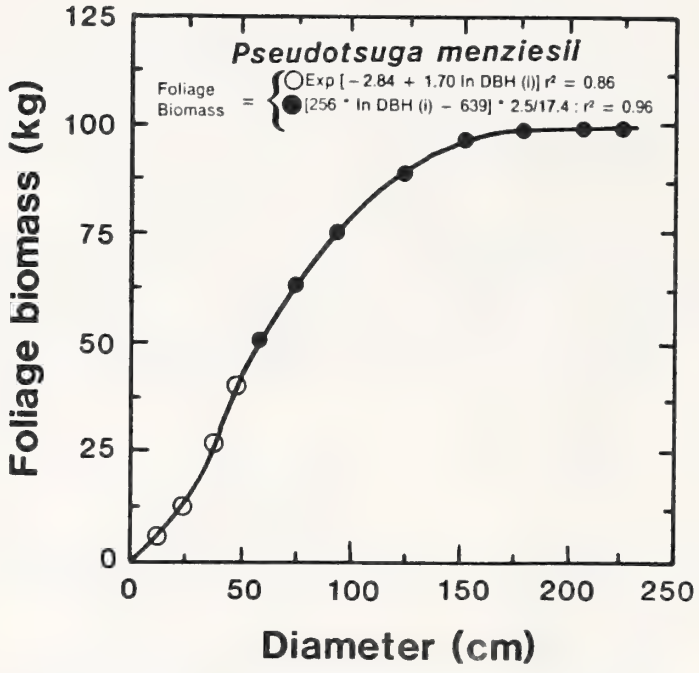

Figure 5.—Foliage biomass as related to diameter for *Pseudotsuga menziesii*.

The equations are as follows:

$$FBIO = \begin{cases} \exp[A_2(i) + BC(i) \ln DBH(k)] & DBH(k) \leq 50,\ i \neq 6 \\ 3.2 + 1.89 \ln (DBH(k)), & DBH(k) \leq 50,\ i = 6 \\ [256 * \ln (DBH(k)) - 639] * 2.5 * DRANGE(i)/C(16), & DBH(k) > 50\ ; \end{cases}$$

where:

$i = 1,...,NSPEC$ (NSPEC = total number of species)
($i = 6 =$ *Alnus rubra*),

$i = 1,...,NTOT$ (NTOT = total number of trees),

$A_2(i)$, $BC(i)$ = parameters from Gholz and others (1979) (see table 7),

$DBH(k)$ = diameter at breast height of tree k (cm),

$DRANGE(i)$ = the ratio of the foliage biomass of species i to that of *P. menziesii* at 50 cm, and

$C(16)$ = conversion from kg to m^2 for *P. menziesii.*

To calculate the leaf area for each tree the foliage biomass is multiplied by the factor $C(i)$ to convert from kg to m^2 and is divided by 2.0 for deciduous trees and 2.5 for conifers to convert total leaf area to projected leaf area.[2/] The projected leaf areas are then summed for all trees and divided by the plot size (2000 m^2) to obtain a value for square meter of leaf area per square meter of ground surface:

$$XLAI = \sum_{k=1}^{NTOT} \frac{C(i)\ FBIO/P(i)}{2000}\ ;$$

where: $P(i) = \begin{cases} 2.0 \text{ if } i \text{ is a deciduous tree and} \\ 2.5 \text{ if } i \text{ is a coniferous tree .} \end{cases}$

The projected leaf area of the plot is tested against the maximum leaf area at which available species can regenerate. If the projected leaf area is less than the species maximum, a random number of saplings (from 1 to 8) enters the plot. Each introduced sapling has a randomly selected diameter of 10 to 15 cm (3.9 to 5.9 in).

Sprouting may occur depending on tree size (subroutine SPROUT). Species that reproduce vegetatively in this manner are *Acer macrophyllum, Alnus rubra, Castanopsis chrysophylla, Quercus garryana,* and *Arbutus menziesii.*

BIRTH continues until the projected leaf area exceeds 1.0 m^2/m^2 resulting in full stocking the first year of the model run.

[2/] Leaf area conversions from personal communication, R. H. Waring, School of Forestry, Oregon State University, Corvallis, Oregon, based on Grier and Waring (1974).

Subroutine GROW

Subroutine GROW calculates diameter increment for each tree (fig. 6). The annual diameter increment function is similar to that used by Botkin and others (1972), Shugart and West (1977), and Mielke and others (1978). CLIMACS is unique in that it incorporates a specific function for the effect of soil moisture upon growth. Diameter growth takes into account the following conditions:

1. Growth per year is dependent upon existing foliage biomass
2. Growth decreases as tree size increases
3. Temperature affects photosynthetic rate
4. Available moisture affects growth
5. Competition influences growth
6. Shading and shade tolerance affect growth.

Optimum Growth Per Year

The growth subroutine calculates the maximum growth of a species and modifies that optimal growth by size and site considerations. There is strong evidence that diameter growth is related to existing foliage biomass (Grier and Logan 1977). CLIMACS uses a nonlinear relationship between leaf biomass and growth: to calculate optimal diameter increment $B_1(i)\ FBIO^{B}4^{(i)}$. The parameters for this relationship are adjusted from those of Reed and Clark (1979) to give reasonable diameter increments for trees 50 cm (19.7 in) in diameter.

Decreases in Growth Rate Related to Size

As a tree increases in size, an increasing portion of its photosynthetic output is used in respiration and not in producing additional tissue. The phenomenon of decreasing growth in large trees is represented by the following calculation from Botkin and others (1972):[3/]

$$1 - \frac{DBH(j)}{DBHMX(i)} \quad \frac{HT(j)}{HMAX(i)} ;$$

for species i and tree j.

As a tree becomes very large, growth approaches zero. Maximum diameter and height were chosen for each species to represent large but not the largest trees of a species to avoid record-sized stands.

[3/] Symbols are defined in table 5 and parameter values given in table 7. Because growth is conditioned by the maximum diameter and height for the species, the maximum values determine the upper limit for tree growth. When using the data for record trees (Fowles 1965, Pardo 1973) the model always grows Site 1 trees. The current values for DBHMX(i) and HMAX(i) are for large but not the largest trees of a species (from Franklin and Dyrness 1973).

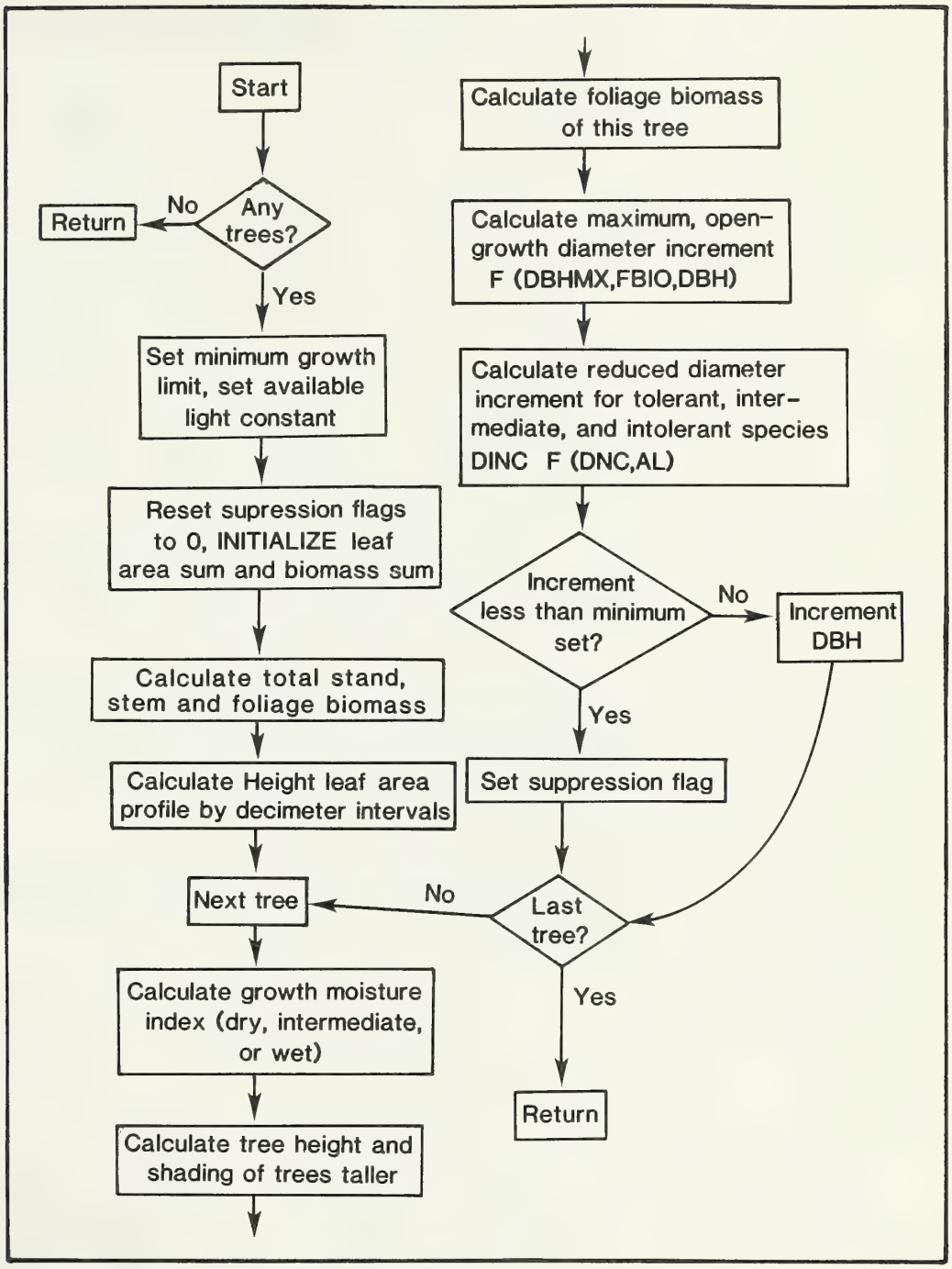
Start
Any trees?
No
Return
Yes
Set minimum growth limit, set available light constant
Reset supression flags to 0, INITIALIZE leaf area sum and biomass sum
Calculate total stand, stem and foliage biomass
Calculate Height leaf area profile by decimeter intervals
Next tree
Calculate growth moisture index (dry, intermediate, or wet)
Calculate tree height and shading of trees taller
Calculate foliage biomass of this tree
Calculate maximum, open-growth diameter increment F (DBHMX,FBIO,DBH)
Calculate reduced diameter increment for tolerant, intermediate, and intolerant species DINC F (DNC,AL)
Increment less than minimum set?
No
Increment DBH
Yes
Set suppression flag
Last tree?
No
Yes
Return

Figure 6.—Flow chart for subroutine GROW.

Table 10—Regression values for height as compared to diameter where $HT = 137 + B_2\ DBH + B_3\ DBH^2$ *

Species	Stressed or nonstressed[1/]	B_2	B_3	R^2	N	D.b.h. range
						Centimeters
Pseudotsuga menziesii	Stressed	72.34	-0.22	0.98	55	9.8 - 196.4
	Nonstressed	80.44	-.23	.96	65	22.3 - 200.4
Tsuga heterophylla	Stressed	75.97	-.27	.98	38	4.9 - 143.4
	Nonstressed	81.21	-.27	.97	39	6.8 - 130.0
Abies procera	Stressed	68.29	-.19	.98	24	48.1 - 127.3
Abies amabilis	Nonstressed	85.60	-.55	.98	19	16.7 - 62.0
Tsuga mertensiana	Nonstressed	55.29	-.07	.98	23	32.2 - 84.2
Thuja plicata	Nonstressed	64.71	-.23	.98	38	6.2 - 157.9

*Data is from research stands in the H. J. Andrews Experimental Forest.

1/Stressed trees are growing in a habitat where PMS < 15 or TGI > 60.

The height-diameter relationship used for some species is based on that used by Botkin and others (1972) and Mielke and others (1978). The parabolic equation follows from a discussion in Ker and Smith (1955). Height (HT) is a function of the diameter at breast height (DBH):

$$HT(j) = 137 + B_2(i)\ DBH(j) - B_3(i)\ DBH(j)^2.$$

The constants $B_2(i)$ and $B_3(i)$ are chosen so that height is at a maximum and the rate of change of height with respect to diameter is zero ($dHT(j)/dDBH(j) = 0$) when $DBH(j)$ is at a maximum:

$$B_2(i) = \frac{2(HMAX(i) - 137)}{DBHMX(i)}, \text{ and}$$

$$B_3(i) = \frac{HMAX(i) - 137}{DBHMX(i)^2}.$$

The rate of change in height decreases as the diameter increases. For *Tsuga heterophylla, T. mertensiana, Thuja plicata, Pseudotsuga menziesii, Abies amabilis,* and *A. procera* height was estimated directly from diameter using equations developed by regression analyses of diameter-height data from the H.J. Andrews Experimental Forest (Willamette National Forest, Oregon) (table 10). Sufficient data were not available to treat all species in this manner. Because height growth is related to habitat and *Tsuga heterophylla* and *P. menziesii* were sampled in a variety of habitats, regressions for these two species were also performed for temperature- or moisture-stressed stands (TGI > 60 or PMS < 15) and nonstressed stands. In stressed stands the height growth is less—particularly for large trees (fig. 7).

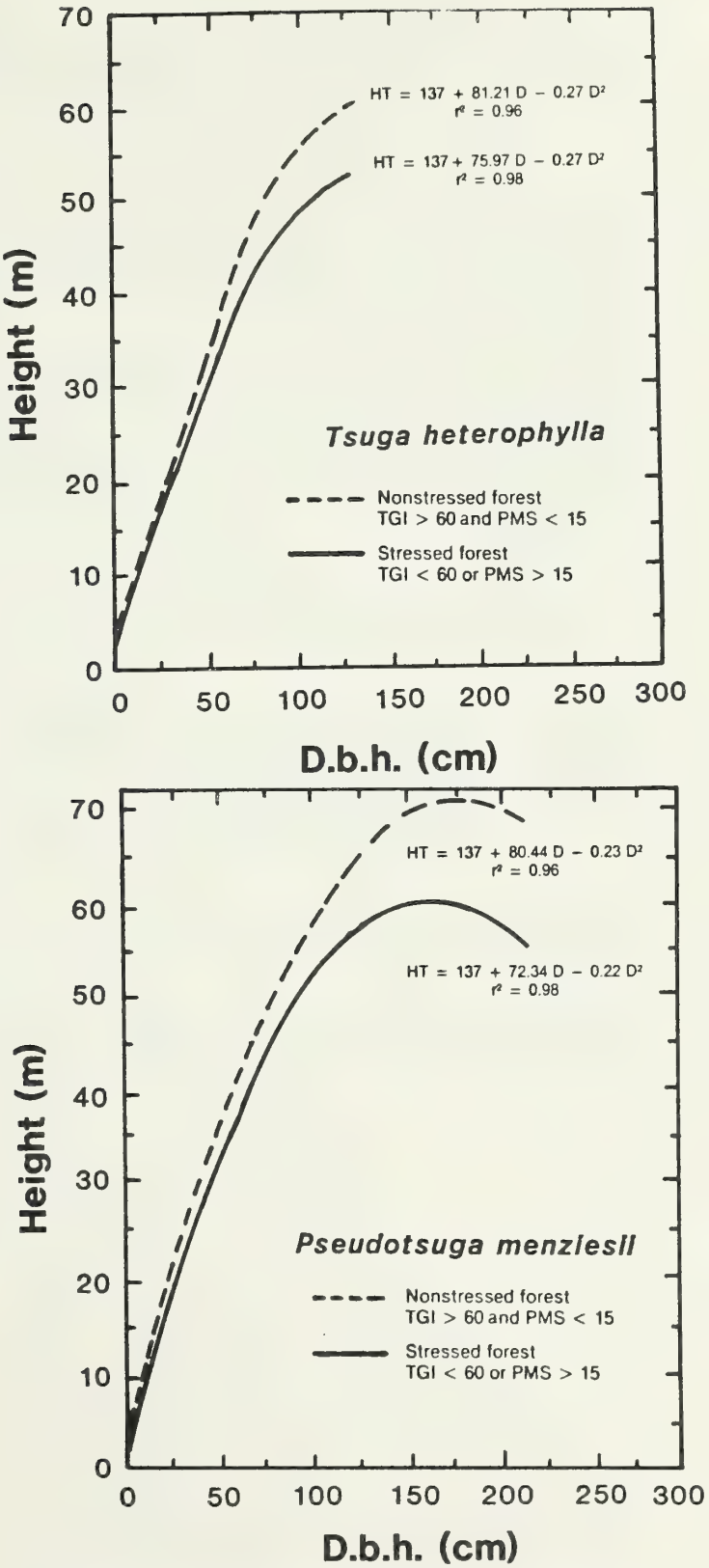

Figure 7.—Tree height as related to diameter for *Tsuga heterophylla* and *Pseudotsuga menziesii* for stressed and nonstressed stands from regression analysis.

Temperature

The effect of temperature on the photosynthetic rate is modeled with a parabolic equation that ranges from 0 to 1 (following Botkin and others 1972):

$$\text{TEGD} = \frac{4(\text{TGI} - \text{DMIN}(i))\ (\text{DMAX}(i) - \text{TGI})}{(\text{DMAX}(i) - \text{DMIN}(i))^2}$$

A value of 0 occurs for TGI less than the minimum degree days (DMIN(i)) or greater than the maximum degree days (DMAX(i)). Thus, this function reflects the temperature range in which a species can grow. The values for DMIN(i) and DMAX(i) are from Emmingham and Waring.[4/]

Effects of Moisture

The inclusion of the moisture index (WATDEX) in the equation for diameter increment is necessary due to the major influence of available moisture on the growth of tree species in the Pacific Northwest (Franklin and Waring 1980). In this model the effect of available moisture on growth is represented by a beta function (following Reed and Clark 1979):

$$\text{WATDEX} = \beta(a,b,c,x) = \begin{cases} \dfrac{(x-a)\ (c-x)^v}{(b-a)\ (c-b)}, & \text{for } x \varepsilon (a,c) \\ 0, & \text{otherwise ;} \end{cases}$$

where: x = PMS,
c = WMIN(i) = the minimum value of water stress for a species (−bars),
a = the negative x-intercept,
b = the optimum PMS for growth (−bars), and
v = $(c-b)/(b-a)$.

See table 11 for a list of the parameter values.

[4/] Personal communication, W. Emmingham and R. H. Waring, School of Forestry, Oregon State University, Corvallis, Oregon.

Table 11—Parameter values for moisture index[1]

Moisture	a	b	Species
Dry	-10	5	Abies grandis, Arbutus menziesii, Acer macrophyllum, Castanopsis chrysophylla, Libocedrus decurrens, Pinus contorta, P. lambertiana, P. ponderosa, Pseudotsuga menziesii, Quercus garryana
Intermediate	-8	1	Abies amabilis, A. lasiocarpa, A. procera, Picea engelmannii, Pinus monticola, Thuja plicata, Tsuga heterophylla, T. mertensiana
Moist	-2	0	Alnus rubra, Chamaecyparis nootkatensis, Picea sitchensis

[1]The parameters, a and b, are explained in the text.

According to the model, dry site species have a high value of WATDEX for most values of PMS (see fig. 8). Intermediate site species, such as *Tsuga heterophylla*, grow only at lower PMS values, and the wet site species, such as *Picea sitchensis*, have a positive value of WATDEX only at very low values of PMS.

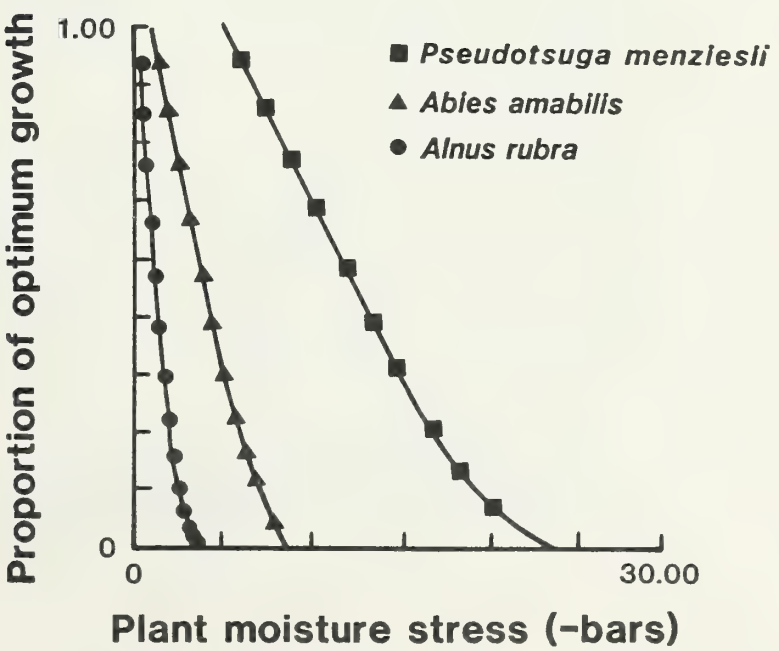

Figure 8.—The effect of plant moisture stress upon diameter increment.

Competition for Nutrients

The crude expression for rooting space competition, which reflects competition for nutrients, is from JABOWA (Botkin and others 1972) and is dependent upon the total aboveground biomass (TBIO) and the maximum biomass a stand can support (SOILQ): 1 − TBIO/SOILQ. The total aboveground biomass (TBIO) is the sum of the foliage biomass and stemwood biomass. The equations for stemwood biomass are from Gholz and others (1979):

$$\text{SBIO} = \begin{cases} 0.02 + 2.09\ \text{DBH}(j) - .0015\ \text{DBH}(j)^2, & i = 6\ (\textit{Alnus rubra}) \\ \exp(A_1(i) + \text{BB}(i)\ \ln\ \text{DBH}(j))\ , & i \neq 6\ ; \end{cases}$$

where $A_1(i)$ and BB(i) are parameter values from Gholz and others (1972) (table 7). The data range for the Gholz equations for stemwood biomass does not include large trees. To assess the impact of this problem stemwood biomass was plotted against values from yield tables (MacLean and Berger 1976) (fig. 9). Modeled and measured biomass values for *Calocedrus decurrens* and *Pinus ponderosa* compare well, but the predicted curve for *Pseudotsuga menziesii* stemwood biomass is greater than measured biomass at large diameters. As there are no data available, evaluation of this discrepancy is not possible.

The maximum biomass for a site (SOILQ) is obtained from recorded values of natural stands similar to the habitat for which the model is being run. As TBIO approaches SOILQ from below, (1-TBIO/SOILQ) approaches 0, and diameter increment decreases. When TBIO exceeds SOILQ, (1-TBIO/SOILQ) becomes negative; no diameter increase occurs. The value for SOILQ should be chosen carefully because evaluation of the model output suggests that the stand biomass is strongly influenced by this value.

Shade Tolerance

Diameter growth is also related to the light a tree receives and its shade tolerance. The regulation of photosynthetic rate by available light is expressed as:

$$1 - \exp(-t_1(\text{AL} - t_2))\ ;$$

where t_1 and t_2 are species specific parameters (see table 12). The available light a tree receives (AL) is based on the total foliage area of all trees in the plot that are taller than the tree being considered (fig. 10 illustrates how available light changes over time). The canopy is broken into tree height intervals by decimeters. The sum of the leaf areas of all trees in height classes greater than the one being considered is calculated and stored as the shading leaf area (SLAR). Available light is then found by using an equation modified from Botkin and others (1972) and Mielke and others (1978):

$$\text{AL} = \text{PHI} * \exp(-0.26\ \text{SLAR})\ ;$$

where PHI = 1.0 is the annual insolation (in appropriate units).

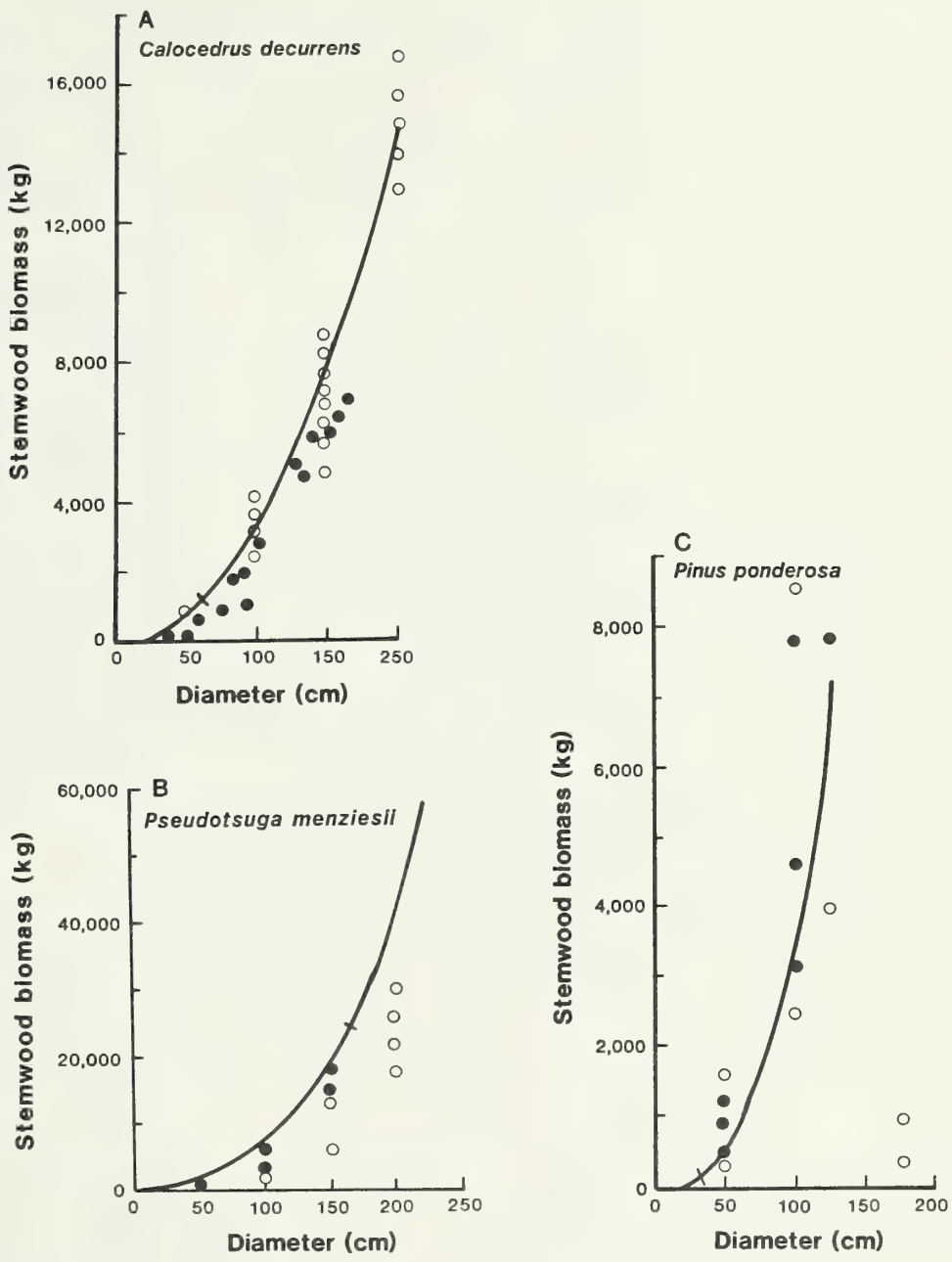

Figure 9.—The relationship of stemwood biomass to diameter for (**A**) *Calocedrus decurrens*, (**B**) *Pseudotsuga menziesii*, and (**C**) *Pinus ponderosa*. The curves are from Gholz and others (1979), and the line crossing the curve indicates the end of the data range. Circles are from volume tables in MacLean and Berger (1976) with solid circles being inside and open circles outside the range of sampled trees.

Table 12—Parameter values for shade tolerance equation

t_1	t_2	Shade tolerance class based on Minore (1979)
23.026	0.30	*Quercus garryana*, *Pinus ponderosa*, *P. contorta*
9.695	.025	*Acer macrophyllum*, *Alnus rubra*, *Castanopsis chrysophylla*, *Arbutus menziesii*, *Picea engelmanni*, *Abies procera*
20.467	.025	*Abies grandis*, *A. lasiocarpa*, *Pinus lambertiana*, *P. monticola* *P. sitchensis*, *Pseudotsuga menziesii*,
32.846	.025	*Libocedrus decurrens*, *Chamaecyparis nootkatensis*, *Thuja plicata*, *T. mertensiana*
40.0	.025	*Abies amabilis*, *Tsuga heterophylla*

[1]The relative diameter growth is equal to $(1-\exp(-t, (AL-t_2)))$ for AL being the available light derived from the projected leaf area (m^2/m^2).

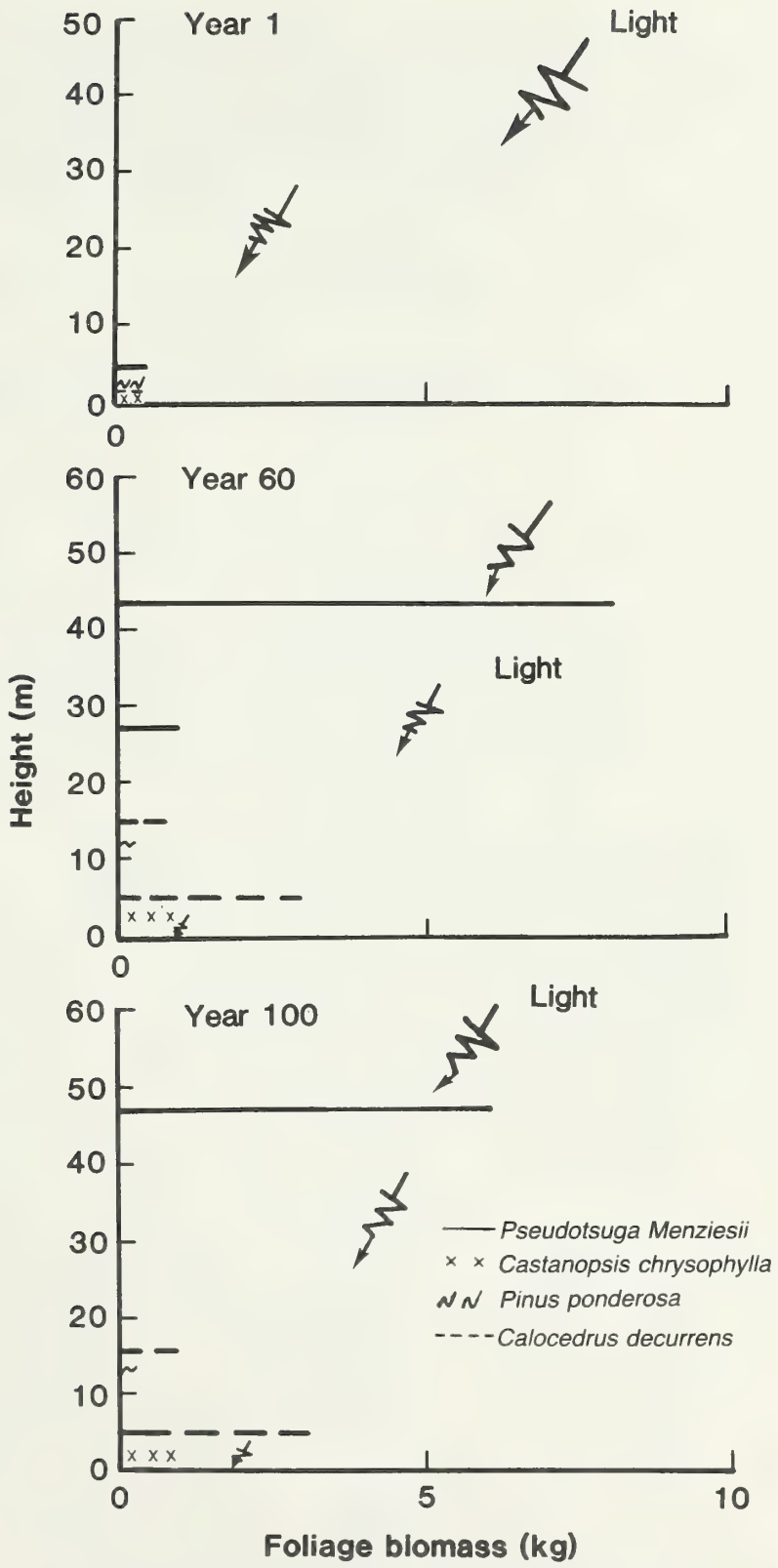

Figure 10.—The relationship of height to foliage biomass from a simulation model. The size of the arrow representing light is meant to depict the amount of light reaching the canopy at each level.

CLIMACS includes five curves that translate available light into photosynthetic capacity based on shade tolerance (fig. 11). *Pinus ponderosa* is the least tolerant of the Pacific Northwest species and cannot grow under a leaf area greater than 5 m^2/m^2 (Minore 1979; Waring).[5/] Hardwoods, intolerant conifers, and tolerant conifers, respectively, represent increasing levels of shade tolerance (Minore 1979). In the model the greatest difference in these categories occurs at a projected leaf area of 8 m^2/m^2.

Diameter Increment Equation

The diameter increment equation is a multiplicative function of six factors:

$$DINC = \left(\frac{1 - DBH(j)\ HT(j)}{DBHMX(i)\ HMAX(i)} \right) \left(\frac{DBH(j)\ B_1(i)\ FBIO^{B4^{(i)}}\ (1-TBIO/SOILQ)TEGD}{274 + 3B_2(i)\ DBH(j)^2 - 4B_3(i)\ DBH(j)^3} \right)$$

$$\times\ (WATDEX) \times [1 - \exp(-a_1(AL-a_2))]\ ;$$

where: $j = 1,...,NTOT$ = the tree number and
$i = 1,...,NSPEC$ = the tree species code.

This assumes that optimum growth is modified by the effects of temperature, moisture availability, competition, and shade tolerance, all acting independently. A multiplicative function is the most common relationship used (Botkin and others 1972, Reed and Clark 1979, Shugart and West 1977) but can tend to underestimate growth if many factors are incorporated (Swartzman and Bentley 1979).

[5/] Personal communication, R. H. Waring, School of Forestry, Oregon State University, Corvallis, Oregon.

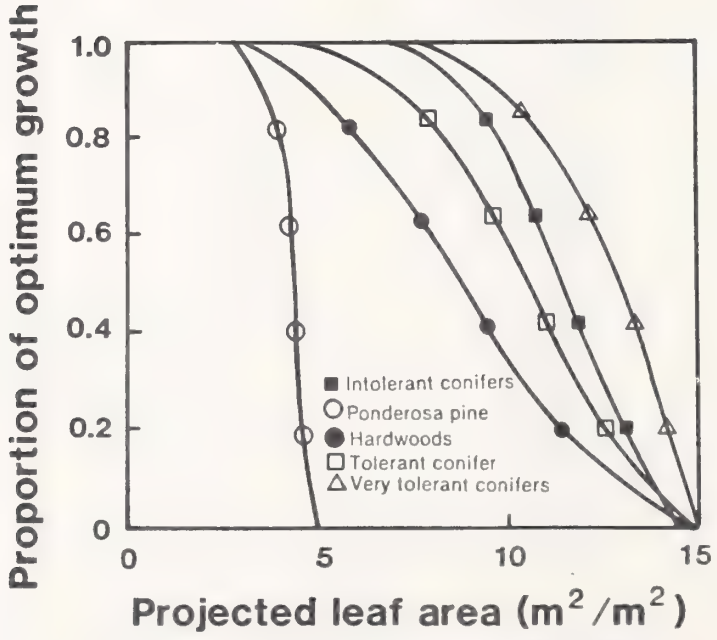

Figure 11.—The effect of shade tolerance on diameter growth.

Subroutine KILL

Much of the existing literature on mortality predicts death of a tree based on its crown quality or vigor class (Graham 1980, Hamilton and Edwards 1976, Staebler 1953). Because we cannot identify crown features in the current model structure, individual tree mortality is based on diameter, the maximum diameter for the species, and the life history of the species (see fig. 12). A tree is subjected to KILL if

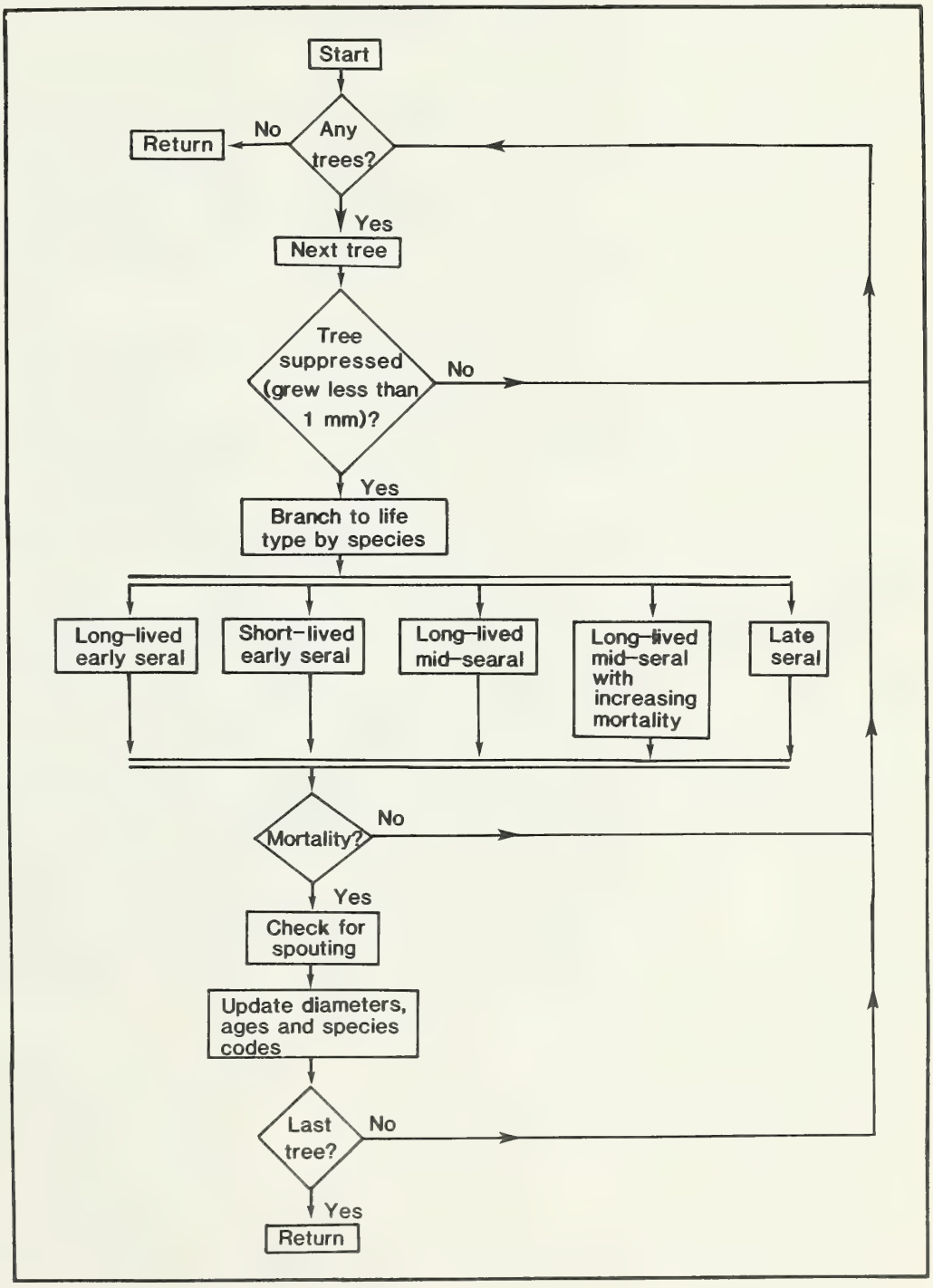

Figure 12.—Flow chart for subroutine KILL.

Table 13—Equations for slow growth-related mortality

Successional status	Conditions	Probability of surviving 1 year	Species
Long-lived early seral	DBH < 0.2DBHMX	$0.8866 + \frac{0.1029}{0.2-1/DBHMX}\left(\frac{DBH-1}{DBHMX}\right)$	*Pinus ponderosa* *Pseudotsuga menziesii*
	DBH ≥ 0.2DBHMX	0.9895	
Short-lived early seral		0.628	*Acer macrophyllum* *Alnus rubra* *Arbutus menziesii* *Quercus garryana*
Long-lived mid-seral	DBH < 0.1 DBHMX	$0.96496 + \frac{0.01294}{.1-1/DBHMX}\left(\frac{DBH-1}{DBHMX}\right)$	*Chamaecyparis nootkatensis* *Libocedrus decurrens* *Thuja plicata*
	DBH ≥ 0.1 DBHMX	$0.97556 + \frac{0.02339\ DBH}{DBHMX}$	
Long-lived mid-seral with increasing mortality	DBH < 0.5DBHMX	$0.8866 + \frac{0.1112}{0.5-1/DBHMX}\left(\frac{DBH-1}{DBHMX}\right)$	*Abies grandis* *A. lasiocarpa* *A. procera* *Picea engelmannii* *P. sitchensis* *Pinus contorta* *P. lambertiana* *P. monticola*
	DBH ≥ 0.5DBHMX	$1.0538 - \frac{0.1112\ DBH}{DBHMX}$	
Late seral	DBH < 0.1 DBHMX	$0.9956 + \frac{0.99335}{0.1-1/DBHMX}\left(\frac{DBH-1}{DBHMX}\right)$	*Abies amabilis* *Tsuga heterophylla* *T. mertensiana*
	DBH ≥ 0.1 DBHMX	$1.0053 - \frac{0.0635\ DBH}{DBHMX}$	

Compiled from McArdle and others (1949) and from unpublished data from a chronosequence of stands in the Cascade Range in Oregon and Washington (Ted Thomas, USFS, Forestry Sciences Laboratory, Corvallis).

diameter growth is less than 1 mm (0.04 in) in any year. We classified tree species into five groups based on mortality pattern using data from a chronosequence of stands in the Cascade Range (table 13). Short-lived, early seral species have a constant survival probability of 0.628 for 1 year. For all other successional classes, mortality changes with the tree size (fig. 13). Long-lived, early seral species have increasing survival until 20 percent of the maximum diameter is reached, at which point the probability of dying becomes constant. Late seral species have an increasing probability of survival until 10 percent of the maximum diameter is attained; then the probability of surviving tapers off slowly. For long-lived, mid-seral species the probability of survival slowly increases as size increases. Long-lived, mid-seral species with increasing mortality have a peak of surviving at 50 percent of the maximum diameter; the probability of death increases on either side of this asymptote.

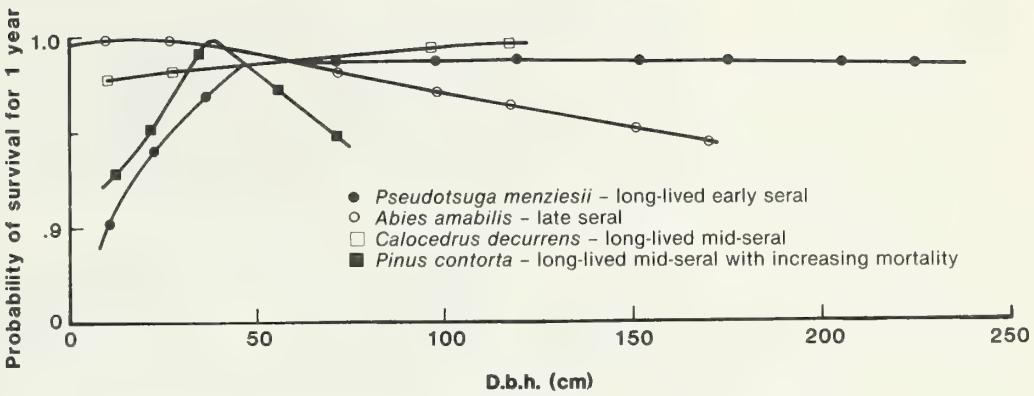

Figure 13.—Probability of tree survival 1 year after slow growth (less than 1 mm [0.04 in] of diameter increment) for four successional classes. A fifth class, short-lived early-seral species, has a constant survival probability of 0.628.

Subroutine DISTRB

The subroutine DISTRB models natural and human disturbances to the ecosystem. Fires are the most common natural disturbances to forests of the Pacific Northwest (Hemstrom 1979), and windthrows can cause localized disturbances. Clearcuttings are simulated on user-specified rotation bases with *Pseudotsuga menziesii* planted after the cut (other species could be planted). Each of these disturbances can be introduced at user-specified intervals and intensities (see subroutine INPUT, Appendix 1).

Because the BIRTH subroutine results in small trees (that is, the seedling stage is skipped), model year 1 is approximately stand year 30 (assuming a 10- to 15-cm (3.9- to 5.9-in) tree is found on a 30-year-old-stand). A disturbance should be thought of as occurring approximately 30 years in the past. Thus a disturbance interval of 100 years results in the disturbance occurring in model years 100, 200, 300, etc., or in stand years 130, 260, 390, etc.

Following an episodic disturbance, the species, the diameter, and the age of all trees killed can be printed out in tabular form and can be saved on a tape for further use (refer to Appendix 1, subroutine INPUT).

Fire

Fire is modeled as an event that causes a high proportion of death for young trees dependent upon the species' tolerance to fire (fig. 14). *Pseudotsuga menziesii, Pinus ponderosa, P. lambertiana, Picea sitchensis, Abies grandis, A. lasiocarpa, A. procera,* and *Quercus garryana* are the species most resistant to fires (Minore 1979; Franklin[6]); and *Abies amabilis, Tsuga heterophylla,* and *T. mertensiana* usually don't survive fire.[7] The probability of a tree surviving a fire (Pr) is related to the intensity of the fire FI ($0 \leq FI \leq 1$):

$$Pr = \begin{cases} \exp(-0.00255*DBH(j))*FI, & i = 2, 3, 4, 12, 14, 15, 16, 17 \\ \exp(-0.00053*DBH(j))*FI, & i = 5, 6, 7, 8, 9, 10, 11, 13, 18, 21 \\ 0 & i = 1, 19, 20 \ . \end{cases}$$

Fire occurs at user-specified intervals. The present model probably works for severe fires that result in stand replacement but is inappropriate for the more frequent and less intense fires in forests dominated by *Quercus garryana* or *Pinus ponderosa.*

Windthrow

The equations for the probability of death of a tree by a catastrophic wind are based on data from Tar Creek in the Clackamas River drainage (see footnote 6). Individual *Pseudotsuga menziesii, Tsuga heterophylla,* and *Thuja plicata* that died as a result of wind between 1948 and 1958 were recorded. All species have an increasing probability of death from wind as size increases (fig. 15). Although large trees have a large surface area upon which the wind can act, smaller trees are frequently in the path of falling large trees. The equations in the model are dependent on size and are conditioned by species and size:

$$P = \begin{cases} (1.6 - \exp(-0.00255*DBH(i)))*FI, & i = 11, 19, 20 \\ (1.9 - \exp(-0.00053*DBH(i)))*FI, & i = 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, \\ & \quad 12, 13, 14, 15, 16, 17, 18, 21 \ . \end{cases}$$

Clearcuttings

A clearcutting is modeled as an event that occurs at user-specified rotation times and removes all of the trees. After all trees are removed from a plot, 198 trees per 0.20-ha (0.08-acre) plot of 10- to 15-cm (3.9- to 5.9-in) d.b.h. *Pseudotsuga menziesii* are introduced to mimic the normal planting prescription of 1,000 trees per hectare.

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[6] Personal communication, J. F. Franklin, Pacific Northwest Forest and Range Experiment Station, USDA Forest Service, Corvallis, Oregon.

[7] Personal communication, J. K. Agee, National Park Service Cooperative Park Studies unit, College of Forest Resources, University of Washington, Seattle, Washington.

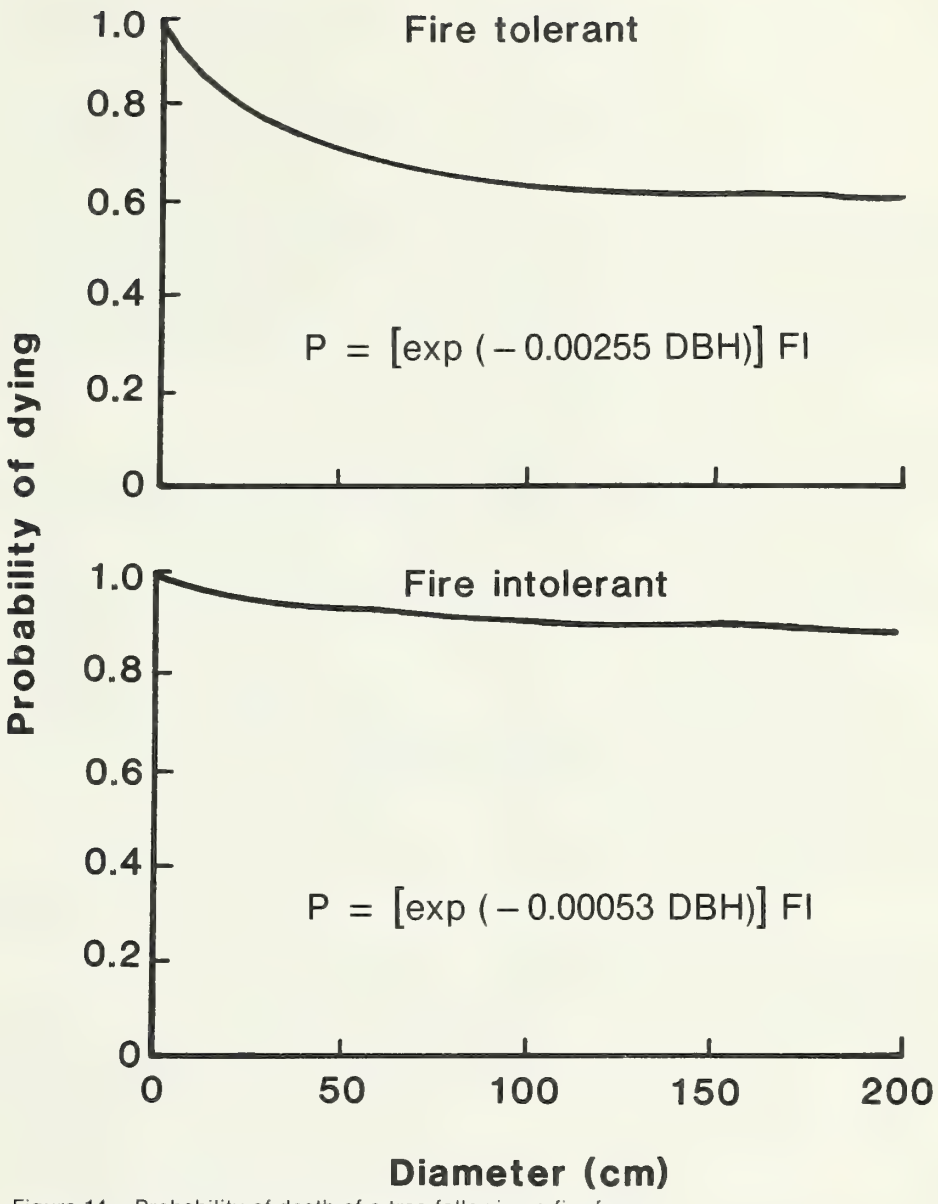

Figure 14.—Probability of death of a tree following a fire for fire-tolerant and fire-intolerant species. *Abies amabilis*, *Tsuga heterophylla*, and *T. mertensiana* do not survive fires in the model. The intensity of the fire can be adjusted by the parameter FI. The most severe fire is depicted (FI = 1).

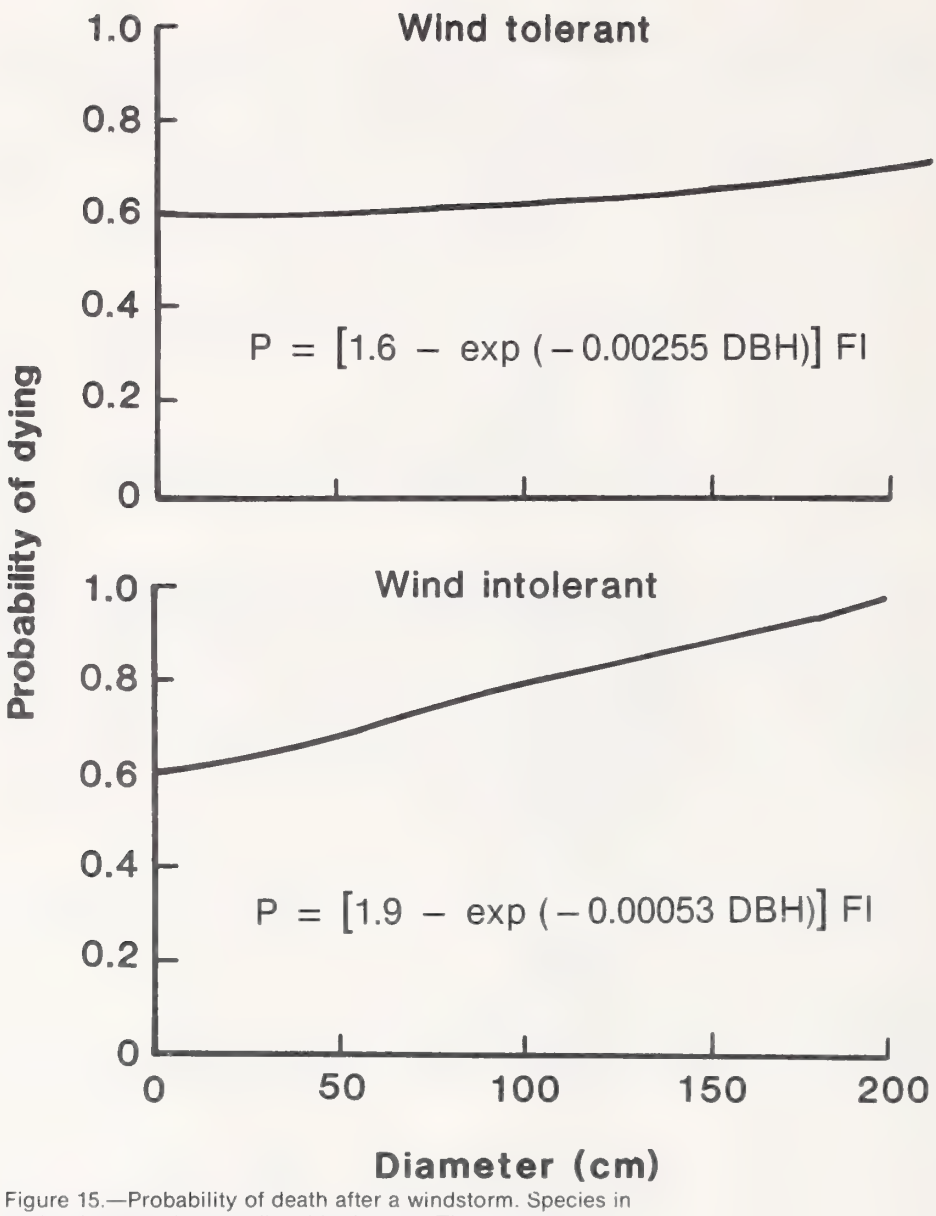

Figure 15.—Probability of death after a windstorm. Species in each tolerance class are listed in the text. The most severe storm is illustrated (FI = 1).

Biological Support of the Model

Biological support of the model is based on three criteria:

1. Scientific rationale of equations and parameter values,
2. Applicability of this model paradigm to at least five forest systems, and
3. Model output compared to data.

CLIMACS has been verified through evaluation of the model equations and parameter values as explained in this text. All relationships and values are based on current knowledge of the tree species of the Pacific Northwest. For large trees, little information exists on the height, stemwood biomass, and foliage biomass relationships to diameter. No studies have documented the change in temperature growth index, plant moisture stress, or leaf area as a stand develops.

The FORTRAN code for CLIMACS is based on models that have been applied to other regions. JABOWA (Botkin and others 1972) simulates forest succession in the northeast United States. Shugart and West (1977) used FORET, the predecessor of CLIMACS, to model the chestnut blight in the Appalachian forest of Tennessee. The FORET model has also been used to project the influence of air pollution on stand development (West and others 1980) and to successfully simulate forest development for a mixed pine-hardwood forest in Arkansas (Mielke and others 1978). Other models derived from the core paradigm have been useful in predicting forest changes in eucalyptus forests of Australia (Shugart and Noble 1981) and in a tropical forest (Doyle and others 1979). Weinstein (1982) examined the diameter increment of a version of FORET and found that the average increment overestimated the diameter changes of trees remeasured after a 13-year interval. This discrepancy was corrected when moisture stress and nutrient limitation were introduced to the model. Both of these factors are in the diameter increment equation in CLIMACS.

Simulations of forests in western Oregon compare well to existing stand structure (Hemstrom and Adams 1982). For xeric and mesic stands nearly 450 years old, CLIMACS projects a stand dominated by *Pseudotsuga menziesii* of a variety of size classes. Projected leaf area, basal area, and foliage biomass of the simulated stand are similar to those of the natural stand (see discussion in Hemstrom and Adams 1982). Differences between the natural and the simulated stand may be due largely to chance and the lack of disturbances in the model forest.

Other comparisons incorporate natural disturbances in the simulation. Projections of 750 years of stand development on the western Olympic Peninsula of Washington State in the aftermath of fire, windstorm, or clearcutting show the major role *Pseudotsuga menziesii* plays (Adams and others 1983). When these disturbances occur at various frequencies, each disturbance results in unique patterns of stand development (Dale and others 1984).

Sensitivity Analysis

A sensitivity analysis is a process to evaluate how sensitive model output is to variation in parameter values. By varying parameters singly and in combination (for those known to be correlated), the influence of the parameter values on model behavior can be assessed. A sensitivity analysis has not been performed on CLIMACS because of a lack of time and money, and we urge that such a study be carried out. In the documentation process, we have noted the sensitivity of the model to the value for the maximum biomass for the forest (SOILQ) and to maximum diameter for each species. The parameters affecting the diameter increment growth, in particular, should be examined carefully. Shugart and West (1979) report that FORET, a forerunner of CLIMACS, is particularly sensitive to plot size. Finn (1979) introduced a form factor to account for crown depth and shading of trees in JABOWA (Botkin and others 1972) and found little effect. Crown form may, nevertheless, affect the development of coniferous forests.

Areas for Improvement

As with any model, CLIMACS can be altered and improved to meet the objectives of the study for which it is being used. Three possible improvements to the model are: (1) altering the mortality curves, (2) changing the vertical structure of each tree, and (3) improving the competition function.

Mortality is a largely unexplored component of successional processes. The model can be used to ask questions about differences in mortality among species by altering the mortality curves (fig. 13) and treating the survival equations as hypotheses to be tested by simulations. A problem with such a simulation study is the lack of data for comparison with model output. Data on survival rates of tagged trees will be available for such a study from permanent plots established by the USDA Forest Service.

The vertical structure of each tree could be modified to more accurately depict the form of a species. This would allow analyses of the role of available habitat for birds and mammals as forests change over time. By correlating breeding habitat to vegetation structure, the probability of a breeding habitat existing under certain management regimes and natural successions could be assessed (for example, Smith and others 1979). These modifications would also allow further study of the impact of leaf area on growth.

The function that models competition for nutrients in the GROW subroutine is a crude approximation. The model applicability would improve by deletion of the parameter SOILQ and incorporation of nitrogen and phosphorus cycling. The problem in including nutrient cycling in the model is depicting an accurate representation but not requiring too many driving variables.

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Appendix 1

Listing of Program CLIMACS

```
(0001)  C     FOREST
(0002)
(0003)  C     .....
(0004)  C     .....FOREST SUCCESSION MODEL
(0005)  C     .....
(0006)  C
(0007)  C     CONVERSION PROGRAMMERS:   J. HOLT, M. RUST
(0008)  C                               MILNE COMPUTER CENTER, OSU.
(0009)  C
(0010)  CQS
(0011)  CQS    All comments labeled "CQS" were done at the Center for Quantitative
(0012)  CQS    science at the University of Washington using the PRIME.  To run the
(0013)  CQS    model on a CDC note these comments and make the appropriate changes.
(0014)  CQS
(0015)  CQS   PROGRAM CONIFER (INPUT,OUTPUT,TAPE4,TAPE5=INPUT,TAPE6=OUTPUT,TAPE8
(0016)  CQS  1)
(0017)  CQS          (FILE DECLARATIONS BELOW)
(0018)  CQS
(0019)        COMMON /FOREST/ NTREES(50),DBH(700),IAGE(1000),KSPRT(50),NEWTR(50)
(0020)       1,SUMLA(1000),NEW(50),NCODE(700),ISEL(50)
(0021)  CQS
(0022)  CQS           PRIME STORES  4 CHARACTERS PER REAL ( 1 REAL = 2 WORDS )
(0023)  CQS           CDC   STORES 10 CHARACTERS PER WORD
(0024)  CQS
(0025)  CQS
(0026)        COMMON /PARAM/ AAA(8,100),DMAX(50),DMIN(50),B3(50),B2(50),ITOL(50)
(0027)       1,AGEMX(50),G(50),SPRTND(50),SPRTMN(50),SPRTMX(50),KTIME(50),A1(50)
(0028)       2,A2(50),BB(50),BC(50),C(50),WMIN(50),IREG(50,4),DBHMX(50),B1(50),
(0029)       3B4(50),HMAX(50),DRANGE(50)
(0030)        COMMON /CONST/ NSPEC,SOILQ,PMS,TGI,TGII,SD,IGEOG
(0031)        COMMON /DEAD/ NOGRO(700)
(0032)        COMMON /COUNT/ NTOT,NYEAR,IPERT,INT,IN,PMORT,FI
(0033)        COMMON /PASSX/ A(501,25),FB(50)
(0034)        COMMON /SEED/ USEED(13)
(0035)        INTEGER USEED
(0036)  CQS
(0037)        DIMENSION Z(2), SPNAM(5,40)
(0038)  CQS
(0039)  CQS      GET SOURCE DEFINITIONS OF K$READ, K$WRIT (TO OPEN FILES)
(0040)  CQS
(0041)
(0042)        NOLIST  /*  SYSCOM>KEYS.F
(0044)        LIST
(0045)
(0046)        DATA  SPNAM              /  200 * '--'  /
(0047)
(0048)        DATA NCT/0/
(0049)
(0050)  CQS   INITIALIZE FILES
(0051)
(0052)        CALL OPEN( 5, 'SUCDAT', 6, K$READ )
(0053)        CALL OPEN( 6, 'OUTPUT', 6, K$WRIT )
(0054)        CALL OPEN( 7, 'TAPE4',  5, K$WRIT )  /* UNIT 4 RESERVED ON PRIME
(0055)        CALL OPEN( 8, 'TAPE8',  5, K$WRIT )
(0056)         CALL OPEN( 9, 'TAPE9', 5, K$WRIT )
(0057)
(0058)
(0059)  C     .....READ INPUT DATA, PARAMETERS, AND VARIABLES FROM TAPE5.
(0060)  C     .....
```

```
(0061)         CALL INPUT
(0062)  C
(0063)  C      ASSIGN FIRST TEN CHARACTERS OF SPECIES NAME TO THE ARRAY USED
(0064)  C      BY THE PLOTTING PROGRAM.
(0065)  C
(0066)         DO 10 I=1,NSPEC
(0067)            CALL STRMOV( AAA(1,I), 1, 10, SPNAM(1,I), 11 )
(0068)     10 CONTINUE
(0069)
(0070)
(0071)         IPLOT = 0
(0072)         KLAST = 1
(0073)         NYR1 = NYEAR+1
(0074)         KTIMES = 1
(0075)         N3 = NSPEC+3
(0076)         DO 20 IVA=1,NYR1
(0077)            DO 20 IVS=1,N3
(0078)               A(IVA,IVS) = 0.
(0079)     20 CONTINUE
(0080)         CALL RANSEE
(0081)  C      .....
(0082)  C      .....PLOT SIZE IS ONE-FIFTH HECTARE.
(0083)  C      .....
(0084)  C      .....SOILQ - THE MAXIMUM BIOMASS RECORDED FOR FORESTS IN THE AREA
(0085)  C      .....THE MAXIMUM LIVE ABOVE-GROUND BIOMASS POSSIBLE IS
(0086)  C      .....1000 TONS/HECTARE
(0087)         SOILQ = 100000.
(0088)  C      .....
(0089)  C      .....TGI - TEMPERATURE GROWTH INDEX
(0090)  C      .....
(0091)  C      .....
(0092)  C      .....NSPEC - NUMBER OF SPECIES FOR SIMULATION
(0093)  C      .....
(0094)     30 CONTINUE
(0095)         CALL PLOTIN (IPLOT)
(0096)         WRITE (6,40) IPLOT,NYEAR
(0097)     40 FORMAT (/,15H  PLOT NUMBER  ,I4,24H TOTAL LENGTH OF RUN IS ,
(0098)       +  I5,6H YEARS////////)
(0099)         KYR = 0
(0100)         CALL OUTPUT (KYR,IPLOT)
(0101)         DO 70 JJ=1,KTIMES
(0102)            CALL INIT
(0103)            DO 60 I=1,NYEAR
(0104)               KYR = I
(0105)         NCT = NCT+1
(0106)         IF(NCT .EQ. 2) GO TO 42
(0107)         CALL GGNORD(12,13,Z)
(0108)         GO TO 44
(0109)     42 Z(1) = Z(2)
(0110)         NCT = 0
(0111)     44 TGI=TGII+SD*Z(1)
(0112)  C             TGI = TGII
(0113)                CALL SELECT
(0114)                CALL KILL (KYR)
(0115)                 IF(IPERT.NE.0.AND.MOD(KYR,INT).EQ.0) CALL DISTRB(KYR)
(0116)                 IF (IPERT.NE.0.AND.  KYR.EQ.1) CALL DISTRB(KYR)
(0117)     45          CALL BIRTH (KYR)
(0118)                CALL GROW(KYR)
(0119)                CALL OUTPUT (KYR,IPLOT)
```

```
(0120)      50        CALL PLTREE (KYR, IPLOT)
(0121)      60     CONTINUE
(0122)      70  CONTINUE
(0123)         IF (IPLOT.NE.KLAST) GO TO 30
(0124)         ZNYR = KLAST
(0125)         DO 110 IV1=1,NYR1
(0126)            TIMEX = IV1-1
(0127)   C        WRITE (7,80) TIMEX
(0128)      80 FORMAT (2E10.3)
(0129)            DO 100 IV2=1,N3
(0130)               A(IV1,IV2) = A(IV1,IV2)/ZNYR
(0131)   C           WRITE (7,80) A(IV1,IV2)
(0132)     100    CONTINUE
(0133)     110 CONTINUE
(0134)   C
(0135)   C      WRITE INFORMATION NEEDED FOR THE PLOT TO FILE TAPE8.
(0136)   C      TAPE8 MAY BE EXAMINED OR THE PLOT PROGRAM APLOT MAY
(0137)   C      BE RUN.
(0138)   C
(0139)   C      WRITE (8,120) NYEAR,NSPEC
(0140)     120 FORMAT (2I8)
(0141)   C      WRITE (8,150) ((SPNAM(I,J),I=1,5),J=1,NSPEC)
(0142)     150 FORMAT (5A4)
(0143)         NNY = NYEAR+1
(0144)         DO 140 I=1,NNY
(0145)   C        WRITE (8,130) (A(I,J),J=1,NSPEC)
(0146)     130 FORMAT (15F8.3)
(0147)     140 CONTINUE
(0148)         CALL EXIT
(0149)         END
```

```
(0001)         SUBROUTINE ADREG(KYR)
(0002)         COMMON /FOREST/ NTREES(50),DBH(700),IAGE(1000),KSPRT(50),NEWTR(50)
(0003)        1,SUMLA(1000),NEW(50),NCODE(700),ISEL(50)
(0004)   CQS
(0005)   CQS    COMMON /PARAM/ AAA(100,3),DMAX(50),DMIN(50),B3(50),B2(50),ITOL(50)
(0006)          COMMON /PARAM/ AAA(8,100),DMAX(50),DMIN(50),B3(50),B2(50),ITOL(50)
(0007)        1,AGEMX(50),G(50),SPRTND(50),SPRTMN(50),SPRTMX(50),KTIME(50),A1(50)
(0008)        2,A2(50),BB(50),BC(50),C(50),WMIN(50),IREG(50,4),DBHMX(50),B1(50),
(0009)        3B4(50),HMAX(50),DRANGE(50)
(0010)          COMMON /CONST/ NSPEC,SOILG,PMS,TGI,TGII,SD,IGEOG
(0011)          COMMON /RAN/ YFL
(0012)          COMMON /DEAD/ NOGRO(700)
(0013)          COMMON /COUNT/ NTOT,NYEAR
(0014)          COMMON /SEED/ USEED(13)
(0015)          INTEGER USEED
(0016)          REAL LA
(0017)   C      .....
(0018)   C      ..... ADVANCE REGENERATION SUBROUTINE (ADREG) DIFFERS FROM GROW IN THAT
(0019)   C      ..... ONLY SHADE TOLERANT CONIFERS ARE ABLE TO GROW.  THIS ROUTINE IS
(0020)   C      ..... CALLED AFTER  WINDTHROWS
(0021)   C      .....
(0022)   C      .....EACH TREE IS REQUIRED TO ADD A 1.0 MM GROWTH RING EACH YEAR
(0023)   C           OTHERWISE THAT TREE IS SUBJECTED TO A POTENTIAL FOR SLOW-
(0024)   C           GROWTH RELATED MORTALITY (SUBROUTINE KILL)
(0025)   C      .....
(0026)         IF (NTOT.EQ.0) RETURN
(0027)         TINC = .1
(0028)         PHI = 1.
(0029)   C      .....
(0030)   C      .....CALCULATE TOTAL NUMBER OF TREES
(0031)   C      .....
(0032)   C      .....
(0033)   C      .....SUM LEAF AREA OF ALL TREES THAT ARE OF APPROXIMATELY
(0034)   C      .....THE SAME HEIGHT
(0035)   C      .....
(0036)         DO 10 I=1,700
(0037)      10 NOGRO(I) = 0
(0038)         DO 20 I=1,1000
(0039)      20 SUMLA(I) = 0.
(0040)         SBIO = 0.
(0041)          IF (NTOT .GT. 700)  CALL ERR
(0042)         DO 50 K=1,NTOT
(0043)            I = NCODE(K)
(0044)   C      .....
(0045)   C      .....CALCULATE STAND BIOMASS, FOLIAGE BIOMASS IN KG, LEAF AREA
(0046)   C           INDEX
(0047)   C      .....
(0048)   C         LA IS THE LEAF AREA (SQ. M) FOR PSME FROM SAPWOOD AREA
(0049)   C
(0050)               LA=(256.*ALOG(DBH(K))-639.)*2.5
(0051)            IF (I.NE.6) GO TO 30
(0052)            HT=137.+B2(6)*DBH(K)-B3(6)*DBH(K)**2
(0053)            SBIO=SBIO+.02+2.09*DBH(K)**2*(HT/100.)/100.-.0015*(DBH(K)**2*
(0054)           1   HT/100.)**2
(0055)            FBIO=3.2+1.89*ALOG(DBH(K))
(0056)             GO TO 31
(0057)      30     SBIO = SBIO+EXP(A1(I)+BB(I)*ALOG(DBH(K)))
(0058)             FBIO=EXP(A2(I)+BC(I)*ALOG(DBH(K)))
(0059)    31       IF(DBH(K).GE.50.)FBIO=LA*(1/C(16))*DRANGE(I)
```

```
(0060)    35        SBIO = SBIO+FBIO
(0061)  C       .....
(0062)  C       .....HEIGHT PROFILE IS CALCULATED IN .1 METER UNITS
(0063)  C       .....
(0064)     40     HIHT = (137+B2(I)*DBH(K)-B3(I)*DBH(K)**2)/10. +1.
(0065)            IF (HIHT.GT.1000) GO TO 150
(0066)            IHT=HIHT
(0067)             IF(I.EQ.5.OR.I.EQ.6.OR.I.EQ.7.OR.I.EQ.17.OR.I.EQ.21)GO TO 45
(0068)            SUMLA(IHT) = SUMLA(IHT)+C(I)*FBIO/5000.
(0069)           GO TO 50
(0070)     45     SUMLA(IHT)=SUMLA(IHT) + C(I)*FBIO/4000.
(0071)     50  CONTINUE
(0072)         DO 60 J=1,999
(0073)            J1 = 1000-J
(0074)            SUMLA(J1) = SUMLA(J1)+SUMLA(J1+1)
(0075)     60  CONTINUE
(0076)  C       .....
(0077)  C       .....CALCULATE AMOUNT OF GROWTH FOR EACH TREE
(0078)  C       .....
(0079)         NG = 1
(0080)         DO 140 J=1,NTOT
(0081)            I = NCODE(J)
(0082)            IF (ITOL(I) .NE.  5) GO TO 140
(0083)  C       .....
(0084)  C       .....CALCULATE MOISTURE - GROWTH INDEX.
(0085)  C       .....
(0086)            GO TO (80,90,80,80,90,70,90,90,70,90,80,90,80,90,70,90,90,80,80
(0087)        1   ,80,90), I
(0088)  C       .....MOIST SITE SPECIES
(0089)     70     V = WMIN(I)/2.
(0090)            WATDEX = (PMS+2. )*(WMIN(I)-PMS)**V/(2.*WMIN(I)**V)
(0091)            GO TO 100
(0092)  C       .....INTERMEDIATE SITE SPECIES
(0093)     80     V = (WMIN(I)-1. )/9.
(0094)            WATDEX = (PMS+8. )*(WMIN(I)-PMS)**V/(9.*(WMIN(I)-1. )**V)
(0095)            GO TO 100
(0096)  C       .....DRY SITE SPECIES
(0097)     90     V = (WMIN(I)-5. )/15.
(0098)            WATDEX = (PMS+10. )*(WMIN(I)-PMS)**V/(15.*(WMIN(I)-5. )**V)
(0099)    100     HT = 137+B2(I)*DBH(J)-B3(I)*DBH(J)**2
(0100)    102     CONTINUE
(0101)            IHT = HT/10. +2.
(0102)    104     CONTINUE
(0103)            SLAR = SUMLA(IHT)
(0104)            AL = PHI*EXP(-SLAR*.26)
(0105)            LA=(256.*ALOG(DBH(J))-639. )*2.5
(0106)            FBIO=EXP(A2(I)+BC(I)*ALOG(DBH(J)))
(0107)            IF(I.EQ.6)FBIO=3.20+1.89*ALOG(DBH(J))
(0108)            IF(DBH(J).GE.50. ) FBIO=LA*(1./C(16))*DRANGE(I)
(0109)    120     A = (1.-(DBH(J)*HT)/(DBHMX(I)*HMAX(I)))
(0110)            B= DBH(J)*B1(I)*FBIO**B4(I)
(0111)            CC = (274+3.*B2(I)*DBH(J)**2-4.*B3(I)*DBH(J)**3)
(0112)            D= (1.-SBIO/SOILQ)*4
(0113)            TEQD = (TQI-DMIN(I))*(DMAX(I)-TQI)/(DMAX(I)-DMIN(I))**2
(0114)            DNC = (A * B / CC) * D * TEQD *WATDEX
(0115)            DINC = (1.-EXP(-32.846*(AL-0.025)))*DNC
(0116)            IF (DBH(J) .LT.  DBHMX(I)) GO TO 121
(0117)            DINC = 0.0
(0118)    121     CONTINUE
```

```
(0119)  C      .....
(0120)  C      .....CHECK INCREMENT LESS THAN 1.0 MM REQUIRED GROWTH
(0121)  C      .....
(0122)  C      ..... WRITE OUT DIAMETER INCREMENT FOR PSME
(0123)  C
(0124)           IF (I .NE. 16) GO TO 125
(0125)           IF (DBH(J) .LE. 86. .OR. DBH(J) .GT. 165.) GO TO 125
(0126)           WRITE (9,122) DINC,KYR
(0127)     122   FORMAT (1X,F9.4,5X,I5)
(0128)     125   CONTINUE
(0129)            IF (DINC.GE.TINC) GO TO 130
(0130)            IF (DINC.LT.0.) DINC = 0.
(0131)            NOGRO(NG) = J
(0132)            NG = NG+1
(0133)     130    DBH(J) = DBH(J)+DINC
(0134)     140 CONTINUE
(0135)         RETURN
(0136)     150 WRITE (6,160)
(0137)     160 FORMAT (19H1 IHT EXCEEDED 1000)
(0138)          STOP
(0139)         END
```

```
(0001)          SUBROUTINE BIRTH (KYR)
(0002)          COMMON /FOREST/ NTREES(50),DBH(700),IAGE(1000),KSPRT(50),NEWTR(50)
(0003)         1,SUMLA(1000),NEW(50),NCODE(700),ISEL(50)
(0004)          COMMON /PARAM/ AAA(8,100),DMAX(50),DMIN(50),B3(50),B2(50),ITOL(50)
(0005)         1,AGEMX(50),G(50),SPRTND(50),SPRTMN(50),SPRTMX(50),KTIME(50),A1(50)
(0006)         2,A2(50),BB(50),BC(50),C(50),WMIN(50),IREG(50,4),DBHMX(50),B1(50),
(0007)         3B4(50),HMAX(50),DRANGE(50)
(0008)          COMMON /CONST/ NSPEC,SOILQ,PMS,TGI,TGII,SD,IGEOG
(0009)          COMMON /RAN/ YFL
(0010)          COMMON /DEAD/ NOGRO(700)
(0011)          COMMON /COUNT/ NTOT,NYEAR,IPERT,INT,IN,PMORT
(0012)          COMMON /SEED/ USEED(13)
(0013)          INTEGER USEED
(0014)          REAL LA
(0015)  C       .....
(0016)  C       .....SAPLINGS ENTER THE PLOT AT AVERAGE SIZE OF 10.0 CM DBH
(0017)  C       .....
(0018)           IF(KYR.LE.20) GO TO 3
(0019)           IF (NTOT.GT.200.  .AND.  MOD(KYR,10) .EQ.  0) GO TO 120
(0020)      3    CONTINUE
(0021)          SIZE = 10.0
(0022)  C       .....
(0023)  C       .....SELECT A SPECIES FROM 1 TO 3 TIMES
(0024)  C       .....
(0025)  C       ....ADD UP NUMBER OF ABAM AND TSHE OF SIZE 10 TO 20 CM SO THAT
(0026)  C       ....  A RESTRICION CAN BE PUT ON THE NUMBER OF BIRTHS.
(0027)  C       ......
(0028)            NABAM = 0
(0029)            NTSHE = 0
(0030)            DO 9 K = 1,NTOT
(0031)              KK=NCODE(K)
(0032)              IF (KK.NE.1) GO TO 5
(0033)              IF (DBH(K).GE.20.  .OR.  DBH(K) .LT.  10.) GO TO 5
(0034)              NABAM = NABAM + 1
(0035)      5       CONTINUE
(0036)              IF (KK.NE.19) GO TO 8
(0037)              IF (DBH(K).GE.20.  .OR.  DBH(K) .LT.  10.) GO TO 8
(0038)              NTSHE = NTSHE + 1
(0039)      8       CONTINUE
(0040)      9       CONTINUE
(0041)          NPLANT = 3.*RANF(6)+1.
(0042)  C       ....
(0043)          DO 100 JK=1,NPLANT
(0044)      10    FBIO = 0.
(0045)  C       .....
(0046)  C       .....CALCULATE BIOMASS (LEAF MASS) FOR EACH SPECIES
(0047)             IF (NTOT.EQ.0) GO TO 40
(0048)             DO 30 K=1,NTOT
(0049)                KK = NCODE(K)
(0050)               LA=(256.0*ALOG(DBH(K))-639.)
(0051)      20        IF(KK.EQ.5.OR.KK.EQ.7.OR.KK.EQ.17.OR.KK.EQ.21) GO TO 25
(0052)             FBIO=EXP(A2(KK)+BC(KK)*ALOG(DBH(K))) *C(KK)/2.5 +FBIO
(0053)              IF(DBH(K).GE.50.) FBIO=FBIO+LA*DRANGE(KK)/2.5
(0054)               GO TO 30
(0055)      25        FBIO=FBIO +EXP(A2(KK)+BC(KK)*ALOG(DBH(K))) *C(KK)/2.0
(0056)               IF(DBH(K).GE.50.) FBIO=FBIO+LA*DRANGE(KK)/2.0
(0057)      30     CONTINUE
(0058)      40     NW = 0
(0059)             XLAI = FBIO/2000.
```

```
(0060)            DO 70 J=1,NSPEC
(0061)               IF (J.EQ.1 .AND. NABAM .GT. 200) GO TO 70
(0062)               IF (J.EQ.19 .AND. NTSHE .GT. 100) GO TO 70
(0063)               IF (ISEL(J).NE.1) GO TO 70
(0064)               IF (XLAI.LT.3.) GO TO 60
(0065)               GO TO (50,50,50,50,50,70,50,50,50,70,50,50,50,70,50,50,70
(0066)         1           ,50,50,50,50),J
(0067)      50       IF (XLAI.LT.6.) GO TO 60
(0068)               GO TO (54,54,54,70,54,54,54,54,54,54,54,54,54,54,54,70,
(0069)         1           54,54,54,54,70), J
(0070)      54       IF (XLAI .LT. 8.) GO TO 60
(0071)               GO TO (58,70,70,58,70,58,70,58,58,58,70,70,70,58,70,58,
(0072)         1           58,58,58,58,58), J
(0073)      58       IF (XLAI .LT. 10.) GO TO 60
(0074)               GO TO (60,60,60,60,60,60,60,70,70,60,60,60,60,60,60,60,60,
(0075)         1            70,60,70,60), J
(0076)      60       NW = NW+1
(0077)               NEWTR(NW) = J
(0078)      70    CONTINUE
(0079)   C     .....
(0080)   C     .....CHECK TO SEE IF THERE ARE ANY NEW TREES
(0081)   C     .....
(0082)            IF (NW.EQ.0) GO TO 90
(0083)   C     .....
(0084)   C     .....CALCULATE AGE AND DIAMETER FOR NEW TREES
(0085)   C     .....
(0086)   C     .....
(0087)   C     .....DETERMINE THE NUMBER OF SEEDLINGS TO PLANT  0 TO 8
(0088)   C     .....
(0089)            MPLANT = RANF(9)*8.
(0090)   C     .....
(0091)   C     .....SELECT SEEDLINGS (PARTICULAR SPECIES)
(0092)   C     .....
(0093)            NW = NW*RANF(10)+1.0
(0094)            NSP = NEWTR(NW)
(0095)   C     .....
(0096)   C     .....PLANT RANDOM NUMBER OF SEEDLINGS
(0097)   C     .....
(0098)            DO 80 J=1,MPLANT
(0099)               NTOT = NTOT+1
(0100)               IF (NTOT.GT.700) CALL ERR
(0101)               IAGE(NTOT) = 0
(0102)               NCODE(NTOT) = NSP
(0103)   C     .....
(0104)   C     .....CALCULATE DBH FOR SEEDLINGS
(0105)   C     .....
(0106)               DBH(NTOT) = SIZE+5.*(1.0-RANF(11))**3
(0107)               NTREES(NSP) = NTREES(NSP)+1
(0108)      80    CONTINUE
(0109)      90    CONTINUE
(0110)            CALL SPROUT
(0111)   C     .....
(0112)   C     .....BIRTH CONTINUED UNTIL LAI .GE. 1.
(0113)   C     .....
(0114)            XLAI = FBIO/2000.
(0115)            IF (XLAI.LT.1.) GO TO 10
(0116)     100 CONTINUE
(0117)   C     .....
(0118)   C     .....INCREMENT AGES
(0119)   C     .....
(0120)         DO 110  I=1,NTOT
(0121)            IAGE(I) = IAGE(I)+1
(0122)     110 CONTINUE
(0123)     120  CONTINUE
(0124)         RETURN
(0125)         END
```

```
(0001)          SUBROUTINE DISTRB(KYR)
(0002)          COMMON /FOREST/ NTREES(50),DBH(700),IAGE(1000),KSPRT(50),
(0003)         1 NEWTR(50),SUMLA(1000),NEW(50),NCODE(700),ISEL(50)
(0004)          COMMON /PARAM/ AAA(8,100),DMAX(50),DMIN(50),B3(50),B2(50),ITOL(50)
(0005)         1,AGEMX(50),G(50),SPRTND(50),SPRTMN(50),SPRTMX(50),KTIME(50),A1(50)
(0006)         2,A2(50),BB(50),BC(50),C(50),WMIN(50),IREG(50,4),DBHMX(50),B1(50),
(0007)         3B4(50),HMAX(50),DRANGE(50)
(0008)   CQS
(0009)          COMMON /CONST/ NSPEC,SOILQ,PMS,TQI,TQII,SD,IGEOG
(0010)          COMMON /COUNT/ NTOT,NYEAR,IPERT,INT,IN,PMORT,FI
(0011)          COMMON /SEED/ USEED(13)
(0012)          INTEGER USEED
(0013)          IF (IPERT.EQ.0) RETURN
(0014)          IF (IPERT.EQ.1) WRITE(6,16)INT
(0015)          IF (IPERT.EQ.2) WRITE(6,17)INT
(0016)          IF (IPERT.EQ.3) WRITE(6,18)INT
(0017)     16   FORMAT (1HO,11H FIRE EVERY,I5,6H YEARS)
(0018)     17   FORMAT (1HO,17H WINDSTORMS EVERY,I5,6H YEARS)
(0019)     18   FORMAT (1HO,13H CLEARCUTS ON,I5,9H ROTATION)
(0020)          IF(IPERT .NE. 1) GO TO 65
(0021)   C
(0022)   C      FIRE
(0023)   C
(0024)          DO 60 K=1,NTOT
(0025)             I=NCODE(K)
(0026)             P=0.0
(0027)             IF(I.NE.17.OR.I.NE.12.OR.I.NE.14.OR.I.NE.16.OR.I.NE.8)GO TO 30
(0028)   C
(0029)   C          FIRE TOLERANT SPECIES HAVE THE FOLLOWING PROBABILITY
(0030)   C                OF DYING IN A FIRE
(0031)   C
(0032)             P=(EXP(-.00255*DBH(K)))*FI
(0033)             GO TO 40
(0034)     30      P=(EXP(-.00053*DBH(K)))*FI
(0035)    40       IF (RANF(2) .GT. P) GO TO 60
(0036)             NTREES(I)=NTREES(I)-1
(0037)             IF(DBH(K).GT.SPRTMN(I).AND.DBH(K).LT.SPRTMX(I))KSPRT(I)=-1
(0038)                  IF (PMORT .NE. 9) GO TO 50
(0039)                  WRITE (9,45) NCODE(K),DBH(K),KYR
(0040)     45           FORMAT (3X,I3,F6.2,I4)
(0041)     50           CONTINUE
(0042)             DBH(K)=-1
(0043)     60      CONTINUE
(0044)     65     CONTINUE
(0045)          IF (IPERT .NE. 2) GO TO 98
(0046)   C
(0047)   C        LIGHT WINDSTORMS BASED ON THE TAR CREEK DATA (OF J. FRANKLIN)
(0048)   C
(0049)   C        DO 80 K =1,NTOT
(0050)   C            I=NCODE(K)
(0051)   C            IF (I.EQ.16  .OR. I.EQ.13 .OR. I.EQ.12
(0052)   C     1          .OR. I.EQ.14 .OR. I.EQ.4) GO TO 70
(0053)   C            IF (I.EQ.5 .OR. I.EQ.6 .OR. I.EQ.7 .OR. I.EQ.17 .OR.
(0054)   C     1          I.EQ.18 .OR. I.EQ.21 .OR. I.EQ.9 .OR. I.EQ.8)  GO TO 74
(0055)   C            IF (DBH(K) .GT. 60.) GO TO 68
(0056)   C             P = .15 -.001 * DBH(K)
(0057)   C             GO TO 79
(0058)   C  68        P = .07
(0059)   C             GO TO 79
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(0060)  C  70        IF (DBH(K) .GT. 100.) GO TO 72
(0061)  C             P = .13 - .001 * DBH(K)
(0062)  C             GO TO 79
(0063)  C  72        P = .03
(0064)  C             GO TO 79
(0065)  C  74        IF (DBH(K) .GT. 100.) GO TO 78
(0066)  C             P = .30 -.02 * DBH(K)
(0067)  C             GO TO 79
(0068)  C  78        P = .18
(0069)  C
(0070)  C  79         IF(RANF(3) .GT.P) GO TO 80
(0071)  C            NTREES(I) = NTREES(I)-1
(0072)  C            IF(DBH(K).GT. SPRTMN(I).AND.DBH(K).LT.SPRTMX(I))
(0073)  C     1       KSPRT(I)=-1
(0074)  C            DBH(K)=-1
(0075)    80     CONTINUE
(0076)    90     CONTINUE
(0077)  CATASTROPHIC WIND
(0078)          DO 96 K=1,NTOT
(0079)  C          SPRUCE & HEMLOCKS ARE WIND INTOLERANT
(0080)             I = NCODE(K)
(0081)             IF (I.EQ.11 .OR. I .EQ.19 .OR. I.EQ.20) GO TO 92
(0082)                 WRITE(6,91) DBH(K),K
(0083)    91           FORMAT ( F10.3,I5)
(0084)             P=(1-(EXP(-.00255*DBH(K)))+0.6)*FI
(0085)             GO TO 94
(0086)    92       P=(1-(EXP(-.00053*DBH(K)))+0.9)*FI
(0087)    94       IF(RANF(3).GT.P) GO TO 96
(0088)             IF(DBH(K).GT. SPRTMN(I) .AND. DBH(K).LT.SPRTMX(I))
(0089)         1      KSPRT(I)=-1
(0090)                    IF (PMORT .NE. 9) GO TO 95
(0091)                    WRITE (9,45) NCODE(K),DBH(K),KYR
(0092)    95              CONTINUE
(0093)             DBH(K)=-1
(0094)    96     CONTINUE
(0095)    98    IF (IPERT.NE.3) GO TO 110
(0096)  C
(0097)  C        CLEARCUTS
(0098)  C
(0099)          DO 100 K=1,NTOT
(0100)               NTREES(I)=NTREES(I)-1
(0101)                    IF (PMORT .NE. 9) GO TO 99
(0102)                    WRITE (9,45) NCODE(K),DBH(K),KYR
(0103)    99              CONTINUE
(0104)               DBH(K)=-1
(0105)    100        CONTINUE
(0106)    110   CONTINUE
(0107)    148   K1=0
(0108)          DO 150 K=1,NTOT
(0109)             IF(DBH(K).LT.0.) GO TO 150
(0110)             K1=K1+1
(0111)             DBH(K1)=DBH(K)
(0112)             IAGE(K1)=IAGE(K)
(0113)             NCODE(K1)=NCODE(K)
(0114)    150      CONTINUE
(0115)    160   CONTINUE
(0116)          NTOT=K1
(0117)          IF (IPERT .NE. 3) GO TO 180
(0118)  C       AFTER CLEARCUT PLANT PSEUDOTSUGA MENZIESII (OTHER SPECIES COULD BE
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(0119)  C            PLANTED BY MAKING CHANGES IN THE "170" LOOP)
(0120)  C
(0121)          DO 170 J = 1,50
(0122)               NTOT=NTOT + 1
(0123)               IAGE(NTOT)=0
(0124)               NCODE(NTOT)=16
(0125)               DBH(NTOT)= 10.  + 5.  *(1.0-RANF(11))**3
(0126)               NTREES(16) = NTREES(16) + 1
(0127)     170   CONTINUE
(0128)  CC       INCREASE YEAR COUNT BY 30 TO MAKE UP LOSS SINCE THESE TREES
(0129)  CC           WERE INTRODUCED AT 10 CM DBH AFTER THE CLEARCUT.
(0130)  CC
(0131)          KYR=KYR+30
(0132)  CC
(0133)  CC
(0134)  CC       CAUSE ADVANCE REGENERATION BY CALLING SUBROUTINE ADREG AFTER WIND
(0135)          IF (IPERT.NE.2) GO TO 200
(0136)  CC
(0137)     180   DO 190 IT=1,3
(0138)                CALL ADREG(KYR)
(0139)     190   CONTINUE
(0140)     200   CONTINUE
(0141)  CC       SINCE TREES ARE INTRODUCED AT 10 CM DBH, LET MODEL GROW TREES
(0142)  CC           FOR 30 YEARS TO MAKE UP LAG IN GROWTH.
(0143)  CC
(0144)           IF (IPERT.NE.1 .OR.  IPERT .NE.  2) GO TO 220
(0145)           DO 210 I=1,30
(0146)               CALL KILL(KYR)
(0147)               CALL GROW(KYR)
(0148)     210       KYR=KYR+1
(0149)     220    CONTINUE
(0150)          RETURN
(0151)          END
```

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(0001)          SUBROUTINE ERR
(0002)          WRITE (6,10)
(0003)       10 FORMAT (37H1 THE NUMBER OF TREES HAS EXCEEDED 800)
(0004)          STOP
(0005)          END
```

```
(0001)          SUBROUTINE GGNORD (NSEED1,NSEED2,Z)
(0002)          DIMENSION Z(1)
(0003)          DATA PI2/0.62831853E01/
(0004)          K = 0
(0005)          A1 = RANF(NSEED1)
(0006)          A2 = RANF(NSEED2)
(0007)          K = K+1
(0008)          Z(K) = SQRT(-.2E01*ALOG(A1))*SIN(PI2*A2)
(0009)          K = K+1
(0010)          Z(K) = SQRT(-0.2E01*ALOG(A1))*COS(PI2*A2)
(0011)          RETURN
(0012)          END
```

```
(0001)         SUBROUTINE GROW(KYR)
(0002)         COMMON /FOREST/ NTREES(50),DBH(700),IAGE(1000),KSPRT(50),NEWTR(50)
(0003)        1,SUMLA(1000),NEW(50),NCODE(700),ISEL(50)
(0004)   CQS
(0005)   CQS    COMMON /PARAM/ AAA(100,3),DMAX(50),DMIN(50),B3(50),B2(50),ITOL(50)
(0006)          COMMON /PARAM/ AAA(8,100),DMAX(50),DMIN(50),B3(50),B2(50),ITOL(50)
(0007)        1,AGEMX(50),G(50),SPRTND(50),SPRTMN(50),SPRTMX(50),KTIME(50),A1(50)
(0008)        2,A2(50),BB(50),BC(50),C(50),WMIN(50),IREG(50,4),DBHMX(50),B1(50),
(0009)        3B4(50),HMAX(50),DRANGE(50)
(0010)          COMMON /CONST/ NSPEC,SOILG,PMS,TGI,TGII,SD,IGEOG
(0011)          COMMON /RAN/ YFL
(0012)          COMMON /DEAD/ NOGRO(700)
(0013)          COMMON /COUNT/ NTOT,NYEAR
(0014)          COMMON /SEED/ USEED(13)
(0015)          INTEGER USEED
(0016)          REAL LA
(0017)   C      .....
(0018)   C      .....EACH TREE IS REQUIRED TO ADD A 1.0 MM GROWTH RING EACH YEAR
(0019)   C           OTHERWISE THAT TREE IS SUBJECTED TO A POTENTIAL FOR SLOW-
(0020)   C           GROWTH RELATED MORTALITY (SUBROUTINE KILL)
(0021)   C      .....
(0022)          IF (NTOT.EQ.0) RETURN
(0023)          TINC = .1
(0024)          PHI = 1.
(0025)   C      .....
(0026)   C      .....CALCULATE TOTAL NUMBER OF TREES
(0027)   C      .....
(0028)   C      .....
(0029)   C      .....SUM LEAF AREA OF ALL TREES THAT ARE OF APPROXIMATELY
(0030)   C      .....THE SAME HEIGHT
(0031)   C      .....
(0032)          DO 10 I=1,700
(0033)      10 NOGRO(I) = 0
(0034)          DO 20 I=1,1000
(0035)      20 SUMLA(I) = 0.
(0036)          SBIO = 0.
(0037)           IF (NTOT .GT. 700)  CALL ERR
(0038)          DO 50 K=1,NTOT
(0039)             I = NCODE(K)
(0040)   C      .....
(0041)   C      .....CALCULATE STAND BIOMASS, FOLIAGE BIOMASS IN KG, LEAF AREA
(0042)   C           INDEX
(0043)   C      .....
(0044)   C         LA IS THE LEAF AREA (SQ. M) FOR PSME FROM SAPWOOD AREA
(0045)              LA=(256.*ALOG(DBH(K))-639.)*2.5
(0046)             IF (I.NE.6) GO TO 30
(0047)             HT=137.+B2(6)*DBH(K)-B3(6)*DBH(K)**2
(0048)             SBIO=SBIO+.02+2.09*DBH(K)**2*(HT/100.)/100.-.0015*(DBH(K)**2*
(0049)        1    HT/100.)**2
(0050)             FBIO=3.2+1.89*ALOG(DBH(K))
(0051)              GO TO 31
(0052)      30     SBIO = SBIO+EXP(A1(I)+BB(I)*ALOG(DBH(K)))
(0053)              FBIO=EXP(A2(I)+BC(I)*ALOG(DBH(K)))
(0054)     31       IF(DBH(K).GE.50.)FBIO=LA*(1/C(16))*DRANGE(I)
(0055)     35        SBIO = SBIO+FBIO
(0056)   C      .....
(0057)   C      .....HEIGHT PROFILE IS CALCULATED IN .1 METER UNITS
(0058)   C      .....
(0059)      40     HIHT = (137+B2(I)*DBH(K)-B3(I)*DBH(K)**2)/10.+1.
```

```
(0060)            IF (HIHT.GT.1000) GO TO 150
(0061)            IHT=HIHT
(0062)             IF(I.EQ.5.OR.I.EQ.6.OR.I.EQ.7.OR.I.EQ.17.OR.I.EQ.21)GO TO 45
(0063)            SUMLA(IHT) = SUMLA(IHT)+C(I)*FBIO/5000.
(0064)           GO TO 50
(0065)     45     SUMLA(IHT)=SUMLA(IHT) + C(I)*FBIO/4000.
(0066)     50 CONTINUE
(0067)        DO 60 J=1,999
(0068)           J1 = 1000-J
(0069)           SUMLA(J1) = SUMLA(J1)+SUMLA(J1+1)
(0070)     60 CONTINUE
(0071)  C      .....
(0072)  C      .....CALCULATE AMOUNT OF GROWTH FOR EACH TREE
(0073)  C      .....
(0074)        NG = 1
(0075)        DO 140 J=1,NTOT
(0076)           I = NCODE(J)
(0077)  C      .....
(0078)  C      .....CALCULATE MOISTURE - GROWTH INDEX.
(0079)  C      .....
(0080)           GO TO (80,90,80,80,90,70,90,90,70,90,80,90,80,90,70,90,90,80,80
(0081)       1   ,80,90), I
(0082)  C      .....MOIST SITE SPECIES
(0083)     70    V = WMIN(I)/2.
(0084)            WRITE (6,72) I,WMIN(I),V
(0085)     72     FORMAT (6H  I=  ,I3,6H WMIN= ,F6.2,6H  V=  ,F6.2)
(0086)           WATDEX = (PMS+2.)*(WMIN(I)-PMS)**V/(2.*WMIN(I)**V)
(0087)             WRITE (6,73) WATDEX
(0088)     73      FORMAT ( 8H WATDEX= ,F6.2)
(0089)           GO TO 100
(0090)  C      .....INTERMEDIATE SITE SPECIES
(0091)     80    V = (WMIN(I)-1.)/9.
(0092)           WATDEX = (PMS+8.)*(WMIN(I)-PMS)**V/(9.*(WMIN(I)-1.)**V)
(0093)           GO TO 100
(0094)  C      .....DRY SITE SPECIES
(0095)     90    V = (WMIN(I)-5.)/15.
(0096)           WATDEX = (PMS+10.)*(WMIN(I)-PMS)**V/(15.*(WMIN(I)-5.)**V)
(0097)    100    HT = 137+B2(I)*DBH(J)-B3(I)*DBH(J)**2
(0098)    102    CONTINUE
(0099)           IHT = HT/10.+2.
(0100)    104    CONTINUE
(0101)           SLAR = SUMLA(IHT)
(0102)           AL = PHI*EXP(-SLAR*.26)
(0103)           LA=(256.*ALOG(DBH(J))-639.)*2.5
(0104)           FBIO=EXP(A2(I)+BC(I)*ALOG(DBH(J)))
(0105)           IF(I.EQ.6)FBIO=3.20+1.89*ALOG(DBH(J))
(0106)           IF(DBH(J).GE.50.) FBIO=LA*(1./C(16))*DRANGE(I)
(0107)    120    A = (1.-(DBH(J)*HT)/(DBHMX(I)*HMAX(I)))
(0108)           B= DBH(J)*B1(I)*FBIO**B4(I)
(0109)           CC = (274+3.*B2(I)*DBH(J)**2-4.*B3(I)*DBH(J)**3)
(0110)           D= (1.-SBIO/SOILQ)*4
(0111)           TEGD = (TGI-DMIN(I))*(DMAX(I)-TGI)/(DMAX(I)-DMIN(I))**2
(0112)           DNC = (A * B / CC) * D * TEGD *WATDEX
(0113)           DINC = (1.-EXP(-20.467*(AL-0.025)))*DNC
(0114)  C      .....
(0115)  C      .....
(0116)  C      .....CHECK FOR PS CURVE TYPE - PONDEROSA PINE
(0117)  C      .....
(0118)           IF (ITOL(I).EQ.1) DINC = (1.0-EXP(-23.026*(AL-0.30)))*DNC
```

```
(0119)           IF(ITOL(I).EQ.1 .AND. AL.LT.0.3) DINC=0.
(0120)  C      .....
(0121)  C      .....CHECK FOR PS CURVE TYPE - HARDWOODS
(0122)  C      .....
(0123)           IF (ITOL(I).EQ.2) DINC = (1.0-EXP(-9.695*(AL-0.025)))*DNC
(0124)  C      .....
(0125)  C      .....CHECK FOR PS CURVE TYPE - TOLERANT CONIFERS
(0126)           IF (ITOL(I).EQ.4) DINC = (1.-EXP(-32.846*(AL-0.025)))*DNC
(0127)           IF (ITOL(I).EQ.5) DINC = (1.-EXP(-40.0*(AL-0.025)))*DNC
(0128)           IF (DBH(J) .LT. DBHMX(I)) GO TO 121
(0129)           DINC = 0.0
(0130)   121     CONTINUE
(0131)  C      .....
(0132)  C      .....CHECK INCREMENT LESS THAN 1.0 MM REQUIRED GROWTH
(0133)  C      .....
(0134)  C      ..... WRITE OUT DIAMETER INCREMENT FOR PSME
(0135)  C
(0136)           IF (I .NE. 16) GO TO 125
(0137)           IF (DBH(J) .LE. 86. .OR. DBH(J) .GT. 165.) GO TO 125
(0138)           IF (PMORT.NE.2) GO TO 125
(0139)           WRITE (9,122) DINC,KYR
(0140)    122    FORMAT (1X,F9.4,5X,I5)
(0141)    125    CONTINUE
(0142)            IF (DINC.GE.TINC) GO TO 130
(0143)            IF (DINC.LT.0.) DINC = 0.
(0144)            NOGRO(NG) = J
(0145)            NG = NG+1
(0146)    130     DBH(J) = DBH(J)+DINC
(0147)    140 CONTINUE
(0148)        RETURN
(0149)    150 WRITE (6,160)
(0150)    160 FORMAT (19H1 IHT EXCEEDED 1000)
(0151)         STOP
(0152)        END
```

```
(0001)         SUBROUTINE INIT
(0002)         COMMON /FOREST/ NTREES(50),DBH(700),IAGE(1000),KSPRT(50),NEWTR(50)
(0003)        1,SUMLA(1000),NEW(50),NCODE(700),ISEL(50)
(0004)         COMMON /CONST/ NSPEC,SOILQ,PMS,TGI,TGII,SD,IGEOG
(0005)         COMMON /DEAD/ NOGRO(700)
(0006)         DO 10 I=1,NSPEC
(0007)            NOGRO(I) = 0
(0008)            KSPRT(I) = 1
(0009)      10 CONTINUE
(0010)         NSPE1 = NSPEC+1
(0011)         DO 20 I=NSPE1,700
(0012)            NOGRO(I) = 0
(0013)      20 CONTINUE
(0014)  CGS    RND IS THE RANDOM NUMBER GENERATOR ON THE PRIME
(0015)          CALL R=RND(1)
(0016)         RETURN
(0017)         END
```

```
(0001)         SUBROUTINE INPUT
(0002)         COMMON /PARAM/ AAA(8,100),DMAX(50),DMIN(50),B3(50),B2(50),ITOL(50)
(0003)        1,AGEMX(50),G(50),SPRTND(50),SPRTMN(50),SPRTMX(50),KTIME(50),A1(50)
(0004)        2,A2(50),BB(50),BC(50),C(50),WMIN(50),IREG(50,4),DBHMX(50),B1(50),
(0005)        3B4(50),HMAX(50),DRANGE(50)
(0006)         COMMON /CONST/ NSPEC,SOILG,PMS,TGI,TGII,SD,IGEOG
(0007)          COMMON /COUNT/ NTOT,NYEAR,IPERT,INT,IN,PMORT,FI
(0008)         DIMENSION NSELCT(50)
(0009)         READ (5,10) NSPEC,(NSELCT(I),I=1,NSPEC)
(0010)      10 FORMAT (40I2)
(0011)         READ (5,20) TGII,SD,PMS,IGEOG,NYEAR,IPERT,INT,PMORT,IN
(0012)      20 FORMAT (F5.1,2F3.0,I1,5I4)
(0013)   C
(0014)   C ---------------------------------------------------------------------
(0015)   C      NYEAR=LENGTH OF THE MODEL RUN IN YEARS
(0016)   C      IPERT= DISTURBANCE TYPE
(0017)   C         0 NONE
(0018)   C         1 FIRE
(0019)   C         2 WINDTHROW
(0020)   C         3 CLEARCUT
(0021)   C      INT=INTERVAL OF DISTURBANCE  IN YEARS
(0022)   C     PMORT - IF EQUAL TO
(0023)   C           2 = PRINT OUT DIAMETER INCREMENT OF DOUGLAS FIR ON YEARLY BASIS
(0024)   C           7 = PRINT OUT STAND STRUCTURE AT YEAR 700 FOR INPUT INTO NEXT
(0025)   C                 RUN OF THE MODEL
(0026)   C           9 = PRINT OUT MORTALITY INFORMATION: SPECIES, DBH AND YEAR DIED
(0027)   C                 FOR INPUT INTO DECAY MODEL - SEE GRAHAM, R. 1982. PH.D. THESIS
(0028)   C                 AT OREGON STATE UNIVERSITY, P. 112.
(0029)   C
(0030)   C      IN=READ IN STAND STRUCTURE IF NOT 0
(0031)   C        = NUMBER OF TREES TO BE READ IN (THE DATA IS AT THE END OF THE
(0032)   C          FILE SUCDAT)
(0033)   C
(0034)   C ---------------------------------------------------------------------
(0035)          READ (5,25) FI
(0036)      25  FORMAT (F5.2)
(0037)   C      FI= FIRE OR WIND INTENSITY (0<FI<=1)
(0038)   C
(0039)         DO 40 J=1,NSPEC
(0040)            READ (5,30) (AAA(I,J),I=1,5),DMAX(J),DMIN(J),B3(J),B2(J),ITOL(J
(0041)        1    ),AGEMX(J),SPRTND(J),SPRTMN(J),SPRTMX(J),KTIME(J),NUM,A1(J),A2
(0042)        2    (J),BB(J),BC(J),C(J),WMIN(J),(IREG(J,I),I=1,4),DBHMX(J),B1(J),
(0043)        3    HMAX(J),B4(J),DRANGE(J)
(0044)      30 FORMAT (5A4 ,6X,F4.0,1X,2F4.0,F5.0,I1,F4.0,7X,F2.0,2F4.0,I4,3X,I2/
(0045)        1F7.4,F6.3,F7.4,F6.4,1X,F4.1,F3.0,4I1/F4.0,F5.0,F5.0,F3.1,F6.3)
(0046)
(0047)      40 CONTINUE
(0048)   C
(0049)   C        FOR "NONSTRESSED" SITES USE HEIGHT PARAMETERS DERIVED FROM
(0050)   C        REGRESSION ANALYSIS.
(0051)   C
(0052)          IF(TGII .GT. 60.0 .AND. PMS .LT. 15.) GO TO 45
(0053)             B2(16)=72.34
(0054)             B3(16)=0.22
(0055)             B2(19)=75.97
(0056)             B3(19)=0.27
(0057)     45    CONTINUE
(0058)         WRITE (6,50)
(0059)      50 FORMAT (1H1,1H ,6X,7HSPECIES,11X,11HDEGREE DAYS,2X,11HHEIGHT PARA,
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(0060)        12X,4HITOL,2X,5HAGEMX,2X,6HSPRTND,/,26X,3HMAX,3X,3HMIN,4X,2HB3,4X,
(0061)       22HB2/)
(0062)         DO 70 I=1,NSPEC
(0063)            WRITE (6,60) I,(AAA(J,I),J=1,5),DMAX(I),DMIN(I),B3(I),B2(I),
(0064)       1    ITOL(I),AGEMX(I),SPRTND(I)
(0065)      60 FORMAT (1H ,I2,1X,5A4 ,2X,F4.0,3X,F4.0,1X,F5.2,1X,F6.2,3X,I2,3X,
(0066)        1F5.0,4X,F3.0)
(0067)      70 CONTINUE
(0068)         WRITE (6,80)
(0069)      80 FORMAT (////,1H ,6X,7HSPECIES,11X,6HSPRTMN,2X,6HSPRTMX,2X,5HKTIME,
(0070)        16X,2HA1,7X,2HA2,7X,2HBB,7X,2HBC,7X,1HC,6X,4HWMIN/)
(0071)         DO 100 I=1,NSPEC
(0072)            WRITE (6,90) I,(AAA(J,I),J=1,5),SPRTMN(I),SPRTMX(I),KTIME(I),A1
(0073)       1    (I),A2(I),BB(I),BC(I),C(I),WMIN(I)
(0074)      90 FORMAT (1H ,I2,1X,5A4 ,2X,F4.0,4X,F4.0,2X,I6,6(2X,F7.4))
(0075)     100 CONTINUE
(0076)         WRITE (6,110)
(0077)     110 FORMAT (1H1,1H ,6X,7HSPECIES,16X,4HIREQ,6X,5HDBHMX,6X,2HB1,6X,
(0078)        14HHMAX,8X,2HB4,8X,6HDRANGE,/,28X,1H1,2X,1H2,2X,1H3,2X,1H4/)
(0079)         DO 130 I=1,NSPEC
(0080)            WRITE (6,120) I,(AAA(J,I),J=1,5),(IREQ(I,J),J=1,4),DBHMX(I),B1
(0081)       1    (I),HMAX(I),B4(I),DRANGE(I)
(0082)     120 FORMAT (1H ,I2,1X,5A4 ,2X,4I3,3X,F5.0,3(2X,F8.1),2X,F8.3)
(0083)     130 CONTINUE
(0084)         RETURN
(0085)         END
```

```
(0001)          SUBROUTINE KILL (KYR)
(0002)          COMMON /FOREST/ NTREES(50),DBH(700),IAGE(1000),KSPRT(50),NEWTR(50)
(0003)         1,SUMLA(1000),NEW(50),NCODE(700),ISEL(50)
(0004)          COMMON /PARAM/ AAA(8,100),DMAX(50),DMIN(50),B3(50),B2(50),ITOL(50)
(0005)         1,AGEMX(50),Q(50),SPRTND(50),SPRTMN(50),SPRTMX(50),KTIME(50),A1(50)
(0006)         2,A2(50),BB(50),BC(50),C(50),WMIN(50),IREG(50,4),DBHMX(50),B1(50),
(0007)         3B4(50),HMAX(50),DRANGE(50)
(0008)          COMMON /CONST/ NSPEC,SOILQ,PMS,TGI,TGII,SD,IGEOG
(0009)          COMMON /DEAD/ NOGRO(700)
(0010)          COMMON /COUNT/ NTOT,NYEAR,IPERT,INT,IN,PMORT
(0011)          COMMON /SEED/ USEED(13)
(0012)          INTEGER USEED
(0013)          IF (NTOT.EQ.0) RETURN
(0014)          NG = 1
(0015)       10 CONTINUE
(0016)  C       .....
(0017)  C       .....SUPPRESSION MORTALITY
(0018)  C            IS DEPENDENT UPON SPECIES AND SIZE OF TREE
(0019)  C
(0020)  C       .....
(0021)           IF (PMORT .NE. 9 .AND. KYR .NE. 1) GO TO 15
(0022)           WRITE (9,12)
(0023)       12  FORMAT (3X,3H -1,10X,39H DATA FOR DEAD TREES = SPECIES DBH YEAR)
(0024)       15  CONTINUE
(0025)       20 DO 130 K=1,NTOT
(0026)             I = NCODE(K)
(0027)  C       .....CHECK FOR SUPPRESSION
(0028)             IF (NOGRO(NG).NE.K) GO TO 130
(0029)             NG = NG+1
(0030)  C       .....SORT MORTALITY TYPES
(0031)             GO TO (100,80,80,80,50,50,50,60,60,80,80,80,80,30,80,30,50,60,
(0032)         1   100,100,50), I
(0033)  C       .....LONG-LIVED EARLY SERAL SPECIES.
(0034)       30    IF (DBH(K).GT.0.2*DBHMX(I)) GO TO 40
(0035)             P = 0.8866+0.1029/(0.2-1./DBHMX(I))*((DBH(K)-1.)/DBHMX(I))
(0036)             IF (RANF(2).LT.P) GO TO 130
(0037)             GO TO 120
(0038)       40    IF (RANF(2).LT.0.9895) GO TO 130
(0039)             GO TO 120
(0040)  C       .....SHORT-LIVED EARLY SERAL SPECIES.
(0041)       50    IF (RANF(2).LT.0.628) GO TO 130
(0042)             GO TO 120
(0043)  C       .....LONG-LIVED MID SERAL SPECIES.
(0044)       60    IF (DBH(K).GT.0.1*DBHMX(I)) GO TO 70
(0045)             P = 0.96496+0.01294/(0.1-1./DBHMX(I))*(DBH(K)-1.)/DBHMX(I)
(0046)             IF (RANF(2).LT.P) GO TO 130
(0047)             GO TO 120
(0048)       70    P = 0.97556+0.02339*DBH(K)/DBHMX(I)
(0049)             IF (RANF(2).LT.P) GO TO 130
(0050)             GO TO 120
(0051)  C       .....LONG-LIVED MID SERAL SPECIES.  INCREASING MORTALITY.
(0052)       80    IF (DBH(K).GT.0.5*DBHMX(I)) GO TO 90
(0053)             P = 0.8866+0.1112/(0.5-1./DBHMX(I))*(DBH(K)-1.)/DBHMX(I)
(0054)             IF (RANF(2).LT.P) GO TO 130
(0055)             GO TO 120
(0056)       90    P = 1.0538-0.1112*DBH(K)/DBHMX(I)
(0057)             IF (RANF(2).LT.P) GO TO 130
(0058)             GO TO 120
(0059)  C       .....LATE SERAL SPECIES.
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(0060)     100     IF (DBH(K).GT.0.1*DBHMX(I)) GO TO 110
(0061)             P = 0.9956+0.00335/(0.1-1./DBHMX(I))*(DBH(K)-1.)/DBHMX(I)
(0062)             IF (RANF(2).LT.P) GO TO 130
(0063)             GO TO 120
(0064)     110     P = 1.0053-0.0635*DBH(K)/DBHMX(I)
(0065)             IF (RANF(2).LT.P) GO TO 130
(0066)     120     CONTINUE
(0067)             NTREES(I) = NTREES(I)-1
(0068)   C         .....
(0069)   C         .....CHECK TO SEE IF DEAD TREE CAN STUMP SPROUT.  SET KSPRT = -1
(0070)   C         .....IF TREE CAN SPROUT
(0071)   C         .....
(0072)             IF (DBH(K).GT.SPRTMN(I).AND.DBH(K).LT.SPRTMX(I)) KSPRT(I) = -1
(0073)             IF (PMORT .NE. 9) GO TO 126
(0074)     125   FORMAT (3X,I3,F6.2,I4)
(0075)              WRITE (9,125) NCODE(K),DBH(K),KYR
(0076)     126     CONTINUE
(0077)             DBH(K) = -1.0
(0078)     130 CONTINUE
(0079)   C         .....
(0080)   C         .....REWRITE DIAMETERS AND AGES TO ELIMINATE DEAD TREES
(0081)   C         .....
(0082)     140 K = 0
(0083)         DO 150 I=1,NTOT
(0084)             IF (DBH(I).LT.0.) GO TO 150
(0085)             K = K+1
(0086)             DBH(K) = DBH(I)
(0087)             IAGE(K) = IAGE(I)
(0088)             NCODE(K) = NCODE(I)
(0089)     150 CONTINUE
(0090)         NTOT = K
(0091)    160  CONTINUE
(0092)          RETURN
(0093)          END
```

```
(0001)         SUBROUTINE OUTPUT (KYR,IPLOT)
(0002)         COMMON /FOREST/ NTREES(50),DBH(700),IAGE(1000),KSPRT(50),NEWTR(50)
(0003)        1,SUMLA(1000),NEW(50),NCODE(700),ISEL(50)
(0004)         COMMON /PARAM/ AAA(8,100),DMAX(50),DMIN(50),B3(50),B2(50),ITOL(50)
(0005)        1,AGEMX(50),G(50),SPRTND(50),SPRTMN(50),SPRTMX(50),KTIME(50),A1(50)
(0006)        2,A2(50),BB(50),BC(50),C(50),WMIN(50),IREG(50,4),DBHMX(50),B1(50),
(0007)        3B4(50),HMAX(50),DRANGE(50)
(0008)         COMMON /PASSX/ A(501,25),FB(50)
(0009)         COMMON /COUNT/ NTOT,NYEAR,IPERT,INT,IN,PMORT
(0010)         COMMON /CONST/ NSPEC,SOILG,PMS,TQI,TQII,SD,IGEOG
(0011)         DIMENSION BAR(50)
(0012)          REAL LA
(0013)         KYR1 = KYR+1
(0014)         AREA = 0.0
(0015)         TBAR = 0.0
(0016)         TOBAR = 0.0
(0017)         DO 10 I=1,NSPEC
(0018)         FB(I) = 0.
(0019)         A(KYR1,I) = 0.
(0020)      10 BAR(I) = 0.
(0021)         A(KYR1,22) = 0.
(0022)         A(KYR1,23) = 0.
(0023)         A(KYR1,24) = 0.
(0024)         A(KYR1,25)=0.0
(0025)         IF (NTOT.EQ.0) GO TO 50
(0026)         DO 40 J=1,NTOT
(0027)            I = NCODE(J)
(0028)            IF (I.NE.6) GO TO 20
(0029)             HT=137.+B2(6)*DBH(J)-B3(6)*DBH(J)**2
(0030)            BAR(I) = BAR(I)+0.02+2.09*(HT/100.)*DBH(J)-0.0015*(HT/100.)*
(0031)        1   DBH(J)**2
(0032)            FBIO=3.2+1.89*ALOG(DBH(J))
(0033)            GO TO 30
(0034)      20    BAR(I) = BAR(I)+EXP(A1(I)+BB(I)*ALOG(DBH(J)))
(0035)               LA=(256.*ALOG(DBH(J))-639.)*2.5
(0036)            FBIO=EXP(A2(I)+BC(I)*ALOG(DBH(J)))
(0037)             IF(DBH(J).GE.50.) FBIO=LA*(1/C(16))*DRANGE(I)
(0038)      30    BAR(I) = BAR(I)+FBIO
(0039)            A(KYR1,25)=A(KYR1,25)+FBIO*.005
(0040)            FB(I)=FB(I)+FBIO*.005
(0041)          GO TO (32,32,32,32,34,34,34,32,32,32,32,32,32,32,32,32,34,
(0042)        1 32,32,32,34),I
(0043)     32          AREA=AREA + FBIO*C(I)/2.5
(0044)                 GO TO 40
(0045)     34          AREA=AREA + FBIO*C(I)/2.0
(0046)      40 CONTINUE
(0047)      50 CONTINUE
(0048)         DO 60 I=1,NSPEC
(0049)      60 TBAR = TBAR+BAR(I)
(0050)         TBAR = TBAR*0.005
(0051)         DO 70 IV1=1,NSPEC
(0052)            A(KYR1,IV1) = A(KYR1,IV1)+BAR(IV1)*0.005
(0053)      70 CONTINUE
(0054)         ATOT = NTOT
(0055)         N1 = NSPEC+1
(0056)         N2 = N1+1
(0057)         N3 = N2+1
(0058)         A(KYR1,N1) = A(KYR1,N1)+TBAR
(0059)   C     TYR(KYR1) = TBAR
```

```
(0001)         SUBROUTINE PLOTIN (IPLOT)
(0002)         COMMON /FOREST/ NTREES(50),DBH(700),IAGE(1000),KSPRT(50),NEWTR(50)
(0003)        1,SUMLA(1000),NEW(50),NCODE(700),ISEL(50)
(0004)         COMMON /CONST/ NSPEC,SOILQ,PMS,TQI,TQII,SD,IGEOG
(0005)         COMMON /COUNT/ NTOT,NYEAR,IPERT,INT,IN,PMORT
(0006)   C     .....
(0007)   C     .....INITIALIZE VARIABLES TO START SIMULATION ON BARE PLOT
(0008)   C     .....NTREES CONTAINS NUMBER OF TREES FOR EACH SPECIES
(0009)   C     .....DBH CONTAINS DIAMETER AT BREAST HEIGHT FOR EACH TREE
(0010)   C     .....KSPRT IS USED TO FLAG THE TREES THAT CAN SPROUT
(0011)   C     .....AREA CONTAINS THE LOCATION OF EACH TREE
(0012)   C     .....NOGRO IS USED TO FLAG THE TREES THAT DON"T GROW
(0013)   C     .....IAGE CONTAINS THE AGE FOR EACH TREE
(0014)   C     .....
(0015)         IPLOT = IPLOT+1
(0016)         NTOT = IN
(0017)         DO 10 I=1,NSPEC
(0018)            IAGE(I) = 0
(0019)            NTREES(I) = 0
(0020)      10 CONTINUE
(0021)         NSPE1 = NSPEC+1
(0022)         DO 20 I=NSPE1,700
(0023)            IAGE(I) = 0
(0024)      20 CONTINUE
(0025)   C       IF IN NOT EQUAL TO ZERO READ IN TREE SIZES AND SPECIES
(0026)   C       DATA AT END OF DATA FILE SUCDAT
(0027)   C
(0028)          IF (IN .EQ. 0) GO TO 80
(0029)   C
(0030)   C       READ IN THE NUMBER OF TREES OF EACH SPECIES
(0031)   C
(0032)          READ (5,25) (NTREES(I),I=1,NSPEC)
(0033)     25   FORMAT (21I3)
(0034)               READ (5,30) (NCODE(K),DBH(K),K=1,IN)
(0035)      30       FORMAT (7(I3,1X,F6.2,7X))
(0036)      40       CONTINUE
(0037)      50   CONTINUE
(0038)          WRITE (6,60) NTOT
(0039)     60   FORMAT (8H NTOT = , I5)
(0040)         WRITE (6,70) (NCODE(K),DBH(K), K=1,IN)
(0041)     70       FORMAT (1X,7(I5,F6.2))
(0042)     80       CONTINUE
(0043)         RETURN
(0044)         END
```

```
(0001)         SUBROUTINE PLTREE (KYR,IPLOT)
(0002)         COMMON /PARAM/ AAA(8,100)
(0003)         COMMON /FOREST/ NTREES(50),DBH(700),IAGE(1000),KSPRT(50),NEWTR(50)
(0004)        1,SUMLA(1000),NEW(50),NCODE(700),ISEL(50)
(0005)         COMMON /CONST/ NSPEC,SOILQ,PMS,TQI,TQII,SD,IGEOG
(0006)         COMMON /COUNT/ NTOT,NYEAR,IPERT,INT,IN,PMORT
(0007)         COMMON /PASSX/ A(501,25),FB(50)
(0008)         DIMENSION D(25,20)
(0009)         DATA PI/0.314159265E01/
(0010)         KYR1 = KYR+1
(0011)         BAREA=0.
(0012)         DO 5 K=1,NTOT
(0013)            BAREA=BAREA+PI*(DBH(K)/2.)**2
(0014)       5    CONTINUE
(0015)         BAREA=(BAREA * 5.)/10000.
(0016)   C
(0017)   C      PRINT OUT TABLE FOR LAST YEAR
(0018)   C
(0019)         IF (NYEAR.EQ.KYR) GO TO 9
(0020)   C
(0021)   C      WRITE ONTO TAPE8 STAND INFORMATION TO BE USED IN APLOT:
(0022)   C        YEAR, STAND BIOMASS, LEAF AREA, STAND BASAL AREA, &
(0023)   C        BIOMASS FOR ABIES AMABILIS, PSEUDOTSUGA MENZIESII & TSUGA
(0024)   C        HETEOPHYLLA
(0025)   C        RECORDED FOR EVERY OTHER YEAR ONTO TAPE8
(0026)   C
(0027)           IF (MOD(KYR,2) .NE. 0) GO TO 100
(0028)          WRITE (8,8) KYR,A(KYR1,22),A(KYR1,24),BAREA,
(0029)        1      A(KYR,1),A(KYR,16),A(KYR,19)
(0030)     8    FORMAT (7(E10.3,2X))
(0031)   C
(0032)   C       ONLY WRITE OUT TABLE EVERY 50 YEARS
(0033)   C       OR FOR FIRST 5 YEARS
(0034)           IF (KYR.LE.5) GO TO 9
(0035)            IF (MOD(KYR,50) .NE. 0) GO TO 100
(0036)   C
(0037)     9   WRITE (6,10) KYR,IPLOT,TQI,PMS
(0038)      10 FORMAT (1H1,4HYEAR,I6,2X,11HPLOT NUMBER,I6,4X,6HTQI = ,F6.1,4X,
(0039)        16HPMS = ,F6.1,4X,18HGEOGRAPHIC REGION:)
(0040)           GO TO (12,14,16,18),IGEOG
(0041)      12 WRITE (6,13)
(0042)      13 FORMAT (1H+,T86,22H SOUTH OF SANTIAM PASS)
(0043)           GO TO 20
(0044)      14 WRITE (6,15)
(0045)      15  FORMAT (1H+,T86,28H SANTIAM PASS TO MT. RAINIER)
(0046)           GO TO 20
(0047)      16 WRITE (6,17)
(0048)      17  FORMAT (1H+,T86, 22H MT. RAINIER TO CANADA)
(0049)           GO TO 20
(0050)      18 WRITE (6,19)
(0051)      19  FORMAT (1H+,T86, 18H OLYMPIC PENINSULA)
(0052)          BIOM = A(KYR1,22)
(0053)      20 WRITE (6,22) A(KYR1,22),A(KYR1,23),A(KYR1,24)
(0054)      22 FORMAT (1H+,45H TOTAL FOLIAGE BIOMASS PLUS STEM WOOD BIOMASS
(0055)        129H (W/O BARK) TONS PER HECTARE=,F10.5,
(0056)        2/2X,38H TOTAL NUMBER OF TREES PER 1/5 H PLOT=,F6.1,6X,4HLEAF
(0057)        312H AREA INDEX=,F10.5)
(0058)          WRITE (6,27) BAREA, A(KYR1,25)
(0059)      27 FORMAT (1H0,18H THE BASAL AREA IS,F10.2,14H SQ. M/HECTARE,6X,
```

```
(0060)        145H TOTAL FOLIAGE BIOMASS (INCLUDES PETIOLES) IS,F8.3//)
(0061)  C
(0062)  C         CALCULATE THE NUMBER OF TREES IN EACH DIAMETER CLASS (FOR
(0063)  C          EVERY 10 CM).   FIRST INITIALIZE D(I,J) TO ZERO.
(0064)  C
(0065)          DO 31 I=1,NSPEC
(0066)             DO 31 J=1,20
(0067)                D(I,J)=0.0
(0068)      31     CONTINUE
(0069)           KTOT=A(KYR1,23)
(0070)          DO 46 K=1,NTOT
(0071)              I=NCODE(K)
(0072)              DC=DBH(K)/10.
(0073)              IF (DC .GT. 20.) WRITE (6,35) DC
(0074)     35       FORMAT (5H DC= ,F8.2)
(0075)              IDC=IFIX(DC)
(0076)              IF(IDC .GE. 16) IDC=16
(0077)              D(I,IDC)=D(I,IDC) +1.
(0078)      46      CONTINUE
(0079)         WRITE (6,47)
(0080)      47 FORMAT (1H ,6X,7HSPECIES,13X,7H NUMBER,2X,6H ABOVE,1X,
(0081)        +8H FOLIAGE,
(0082)        120X,26H NUMBER PER DIAMETER CLASS/24X,9H OF TREES,1X,
(0083)        27H GROUND,2X,
(0084)        38H BIOMASS,1X,40H  10  20  30  40  50  60  70  80  90 100
(0085)        48H 110 120
(0086)        517H 130 140 150 160+/34X,8H BIOMASS
(0087)        611X,35H-20 -30 -40 -50 -60 -70 -80 -90-100
(0088)        725H-110-120-130-140-150-160 )
(0089)          DO 49 I=1,NSPEC
(0090)             WRITE (6,48) I,(AAA(J,I),J=1,5),NTREES(I),A(KYR,I),FB(I),
(0091)        1(D(I,J),J=1,16)
(0092)      48     FORMAT (1H ,I2,1X,5A4 ,2X,I6,2X,F6.2,2X,F6.2,4X,16(F4.0))
(0093)      49     CONTINUE
(0094)         WRITE (6,50)
(0095)      50 FORMAT ( ///)
(0096)  C   60 WRITE (6,65)
(0097)      65 FORMAT (1H0,41HSPECIES CODES, DIAMETERS, AND AGES FOLLOW)
(0098)  C       WRITE (6,70) (NCODE(K),DBH(K),IAGE(K),K=1,NTOT)
(0099)      70 FORMAT (1H0,7(I3,1X,F6.2,1X,I4,2H--)/(1H0,7(I3,1X,F6.2,1X,I4,2H--)
(0100)        1))
(0101)     100   CONTINUE
(0102)  C
(0103)  C       FOR PMORT=7, PRINT OUT STAND STRUCTURE AT TIME 700 FOR INPUT TO
(0104)  C          NEXT RUN OF CLIMACS
(0105)  C
(0106)           IF (PMORT .NE. 7) GO TO 120
(0107)            IF (KYR .NE. 700) GO TO 120
(0108)           WRITE (9, 110) (NCODE(K),DBH(K),K=1,NTOT)
(0109)     110   FORMAT (7(I3,1X,F6.2,7X))
(0110)     120   CONTINUE
(0111)  C
(0112)          RETURN
(0113)          END
```

```
(0001)          FUNCTION RANDOM (NSEED)
(0002)          COMMON /SEED/ USEED(13)
(0003)          INTEGER USEED
(0004)          ISEED = USEED(NSEED)*100.
(0005)          DUM = RND(ISEED)
(0006)          RANDOM = RND(0)
(0007)          RETURN
(0008)          END
```

```
(0001)          SUBROUTINE RANSEE
(0002)          COMMON /SEED/ USEED(13)
(0003)          INTEGER USEED
(0004)
(0005)          DUM = RND(1)
(0006)
(0007)          DO 10 I = 1,13
(0008)       10 USEED(I) = RND(0)
(0009)
(0010)          RETURN
(0011)          END
```

```
(0001)          REAL*4 FUNCTION RANF( IDUM )
(0002)
(0003)    C     UNIFORM RANDOM NUMBER GENERATOR
(0004)
(0005)          RANF = RND(0)
(0006)
(0007)          RETURN
(0008)          END
```

```
(0001)          SUBROUTINE SELECT
(0002)          COMMON /FOREST/ NTREES(50),DBH(700),IAGE(1000),KSPRT(50),NEWTR(50)
(0003)         1,SUMLA(1000),NEW(50),NCODE(700),ISEL(50)
(0004)          COMMON /PARAM/ AAA(8,100),DMAX(50),DMIN(50),B3(50),B2(50),ITOL(50)
(0005)         1,AGEMX(50),Q(50),SPRTND(50),SPRTMN(50),SPRTMX(50),KTIME(50),A1(50)
(0006)         2,A2(50),BB(50),BC(50),C(50),WMIN(50),IREG(50,4),DBHMX(50),B1(50),
(0007)         3B4(50),HMAX(50),DRANGE(50)
(0008)          COMMON /CONST/ NSPEC,SOILQ,PMS,TQI,TQII,SD,IQEOQ
(0009)          DO 10 I=1,NSPEC
(0010)             ISEL(I) = 0
(0011)    C     .....CHECK MAXIMUM WATER STRESS.
(0012)             IF (WMIN(I).LT.PMS) GO TO 10
(0013)    C     .....CHECK TEMPERATURE REQUIREMENTS.
(0014)             IF (TQI.LT.DMIN(I).OR.TQI.GT.DMAX(I)) GO TO 10
(0015)    C     .....CHECK SPECIES DISTRIBUTIONS.
(0016)    C     .....REGION 1 = SOUTH OF SANTIAM PASS.
(0017)    C     .....REGION 2 = SANTIAM PASS TO MT.  RAINIER NP.
(0018)    C     .....REGION 3 = MT.  RAINIER NP TO CANADIAN BOARDER.
(0019)    C     .....REGION 4 = OLYMPIC NP.
(0020)             IF (IREG(I,IQEOQ).NE.1) GO TO 10
(0021)             ISEL(I) = 1
(0022)       10 CONTINUE
(0023)          RETURN
(0024)          END
```

```
(0001)           SUBROUTINE SPROUT
(0002)          COMMON /FOREST/ NTREES(50),DBH(700),IAGE(1000),KSPRT(50),NEWTR(50)
(0003)         1,SUMLA(1000),NEW(50),NCODE(700),ISEL(50)
(0004)          COMMON /PARAM/ AAA(8,100),DMAX(50),DMIN(50),B3(50),B2(50),ITOL(50)
(0005)         1,AGEMX(50),G(50),SPRTND(50),SPRTMN(50),SPRTMX(50),KTIME(50),A1(50)
(0006)         2,A2(50),BB(50),BC(50),C(50),WMIN(50),IREQ(50,4),DBHMX(50),B1(50),
(0007)         3B4(50),HMAX(50),DRANGE(50)
(0008)           COMMON /CONST/ NSPEC,SOILQ,PMS,TQI,TQII,SD,IGEOG
(0009)           COMMON /DEAD/ NOGRO(700)
(0010)           COMMON /COUNT/ NTOT,NYEAR,IPERT,INT,IN,PMORT
(0011)           COMMON /SEED/ USEED(13)
(0012)           INTEGER USEED
(0013)  C        .....
(0014)  C        .....SMALLEST AVERAGE STUMP SPROUT IS .1 CM
(0015)  C        .....
(0016)           SIZE = .1
(0017)  C        .....
(0018)  C        .....SUM TOTAL NUMBER OF TREES
(0019)  C        .....
(0020)  C        .....DETERMINE WHICH SPECIES CAN SPROUT
(0021)  C        .....
(0022)             NW = 0
(0023)           DO 10 I=1,NSPEC
(0024)              IF (SPRTND(I).LE.0.) GO TO 10
(0025)              IF (KSPRT(I).GE.0) GO TO 10
(0026)              NW = NW+1
(0027)              NEW(NW) = I
(0028)       10 CONTINUE
(0029)  C        .....
(0030)  C        .....CHECK FOR SPROUTS
(0031)  C        .....
(0032)           IF (NW.EQ.0) GO TO 30
(0033)  C        .....
(0034)  C        .....CHOOSE RANDOM NUMBER OF SPROUTS
(0035)  C        .....
(0036)           NW = NW*RANF(3)+1.0
(0037)  C        .....
(0038)  C        .....SELECT SPECIES TO SPROUT
(0039)  C        .....
(0040)           NSPC = NEW(NW)
(0041)  C        .....
(0042)  C        .....SPRTND IS THE TENDENCY FOR THE ITH SPECIES TO STUMP OR
(0043)  C        .....ROOT SPROUT.  THE VALUE OF SPRTND IS THE AVERAGE NUMBER
(0044)  C        .....OF SPROUTS THAT MIGHT OCCUR WITH A TREE DEATH
(0045)  C        .....
(0046)  C        .....
(0047)  C        .....RANDOMLY SELECT NUMBER OF TREES TO SPROUT
(0048)  C        .....
(0049)           NSPRT = RANF(4)*SPRTND(NSPC)+1
(0050)           DO 20 I=1,NSPRT
(0051)              NTREES(NSPC) = NTREES(NSPC)+1
(0052)              NTOT = NTOT+1
(0053)              IF (NTOT.GT.700) CALL ERR
(0054)              IAGE(NTOT) = 0
(0055)              NCODE(NTOT) = NSPC
(0056)              DBH(NTOT) = SIZE+.1*(1.0-RANF(5))**3
(0057)  C        .....
(0058)  C        .....STORE DIAMETERS AND AGES FOR NEW SPROUTS
(0059)  C        .....
```

Appendix 2

Tabular Output of Program CLIMACS

Year 400 Plot Number 1 TGI = 76.0 PMS = 13.0 Geographic region: Olympic Peninsula
Total foliage biomass plus stemwood biomass (without bark) tons per hectare = 499.77795
Total number of trees per 1/5-ha plot = 359.0 Leaf area index = 6.94256
Basal area is 61.25 m^2/ha Total foliage biomass (includes petioles) is 9.454

				Number per diameter class															
Species	Number of trees	Above-ground biomass	Foliage biomass	10 -20	20 -30	30 -40	40 -50	50 -60	60 -70	70 -80	80 -90	90 -100	100 -110	110 -120	120 -130	130 -140	140 -150	150 -160	160+
Abies amabilis	243	27.16	3.13	205	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Abies grandis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Abies lasiocarpa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Obies procera	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acer macrophyllum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Alnus rubra	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Arbutus menziesii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Castanopsis chrysophylla	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chamaecyparis nootkatensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Libocedrus decurrens	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Picea engelmannii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Picea sitchensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pinus contorta	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pinus lambertiana	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pinus monticola	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pinus ponderosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pseudotsuga menziesii	2	411.99	1.02	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Quercus garryana	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Thuja plicata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tsuga heterophylla	293	60.66	5.31	105	45	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Tsuga mertensiana	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Dale, Virginia H.; Hemstrom, Miles. CLIMACS: A computer model of forest stand development for western Oregon and Washington. Res. Pap. PNW-327. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1984.** 60 p.

A simulation model for the development of timber stands in the Pacific Northwest is described. The model grows individual trees of 21 species in a 0.20-hectare (0.08-acre) forest gap. The model provides a means of assimilating existing information, indicates where knowledge is deficient, suggests where the forest system is most sensitive, and provides a first testing ground for hypotheses. Model verification simulations are included for up to 500 years on various sites. Fire, wind, or clearcutting can occur at intervals and intensities specified by users. The model was developed by modifying an existing forest succession simulator of eastern deciduous forests. Birth, growth, and death of individual trees are functions of existing light and temperature conditions, competition and species characteristics. Modifications of the existing simulator include tree height growth being related to temperature and moisture conditions, the foliage biomass to diameter relationship being more realistic, and five mortality classes and shade tolerance classes being defined.

Keywords: Succession, models, simulation, community dynamics (plant).

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